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MULTIPLEX MAPPING EQUIPMENT

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MULTIPLEX MAPPING EQUIPMENT

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SECTION I

GENERAL

1. PURPOSE.—This manual is an operator's handbook for use in training personnel in the operation of multiplex stereoscopic mapping equipment and the employment of this equipment in the preparation of topographic maps. Its purpose is to present the necessary information to operate this equipment and to serve as both a reference manual for the individual operator and a guide for the training of operators.

2. SCOPE.—This manual includes a general discussion of the multiplex method of mapping and its development, a brief description of the principles of the multiplex, a detailed description of the multiplex equipment, detailed instruction for the use of the equipment, and a discussion of the accuracy attainable when this equipment is used in mapping. Included in appendixes are notes on training of operators, notes on plotting, multiplex plotting, and photographic data, and a glossary of the technical terms used in connection with the multiplex equipment and aerial mapping in general. This manual does not discuss fully the merits of the multiplex method of mapping as compared to other methods, nor does it include all of the detailed information needed to plan and prepare a project for this method of mapping. Knowledge of the material contained in existing manuals on map reading and topographic drafting is presupposed.

3. DEVELOPMENT.—**a.** Following the impetus given aerial photography by World War I, the desirability of using that type of photography as an aid to mapping was recognized by the War Department. At first, practice was confined to obtaining planimetric information for various uses, the most advanced being the use of large-coverage, multiple-lens cameras for "radial line" plotting of additional control and the filling in of planimetric detail. Stereoscopic viewing of overlapping pairs of photographs was used only in studying the terrain, no method being then available for precise measurement of accurate stereoscopic "models."

b. Meanwhile, many systems of three-dimensional mapping by using stereoscopic pairs of pictures had been

developed and, with rapid development in aircraft, aerial cameras, and aerial film, their practicability soon became evident. The Corps of Engineers maintains close liaison with the Army Air Forces in order to follow these developments and to make such adaptations and research as are necessary to keep the War Department equipped with the most advantageous types of equipment.

c. As a result of the development work performed by the Corps of Engineers, the multiplex equipment was adopted by the War Department for performing mapping missions of the highest accuracy. The first multiplex equipment procured by the War Department was designed around the then existing camera equipment of the Army Air Forces. The angular coverage of cameras used for mapping at that time was in the vicinity of 70°, which was later termed a "normal" angle. The earliest multiplex equipment procured is therefore known as "normal" equipment. Almost coinciding with the procurement of the first multiplex equipment was the development of cameras to cover wider angles. The result of this development was a camera that covered approximately 93°, which coverage has become known as a "wide-angle." Later procurement of multiplex equipment was designed around this wide-angle camera. The wide-angle multiplex equipment has thus made the normal equipment obsolete, although it will doubtless continue in use until complete replacement is possible.

4. STEREOSCOPIC MAPPING.—a. Within certain limits, a stereoscopic view of any subject may be obtained by fusing two pictures of the subject taken from different viewpoints so that each eye will see but one view. However, this view or "model" is generally not a true-to-scale reproduction of the subject. Each picture is a perspective view of the subject, the camera lens being the center of perspective. In order to have a true perspective view, the taking lens must be without distortion or the picture must be viewed through the taking lens, or a lens exactly like it. Assuming two true perspective views, to obtain a correct stereoscopic model the two views must be fused with exactly the same angular relationship as occurred in nature when the pictures were taken. Practically, this means the taking positions and orientations of the two pictures must be recovered. For aerial photographs, this is not possible by any system of direct measurement.

b. A true stereoscopic model can be formed from two correct perspective views if the pictures can be projected from the same or similar cameras so that all rays from corresponding picture points intersect in space. To do this with certainty and to obtain a model that can be used for mapping, the following requirements must be fulfilled:

(1) A stable original negative (on glass plate or good film).

(2) Projection from an exact duplicate of the taking camera or from an exact reduction or enlargement of the taking camera; in the latter case the same reduction or enlargement of the photograph must be made.

(3) A precise method of orienting the two projections, both relatively and absolutely.

(4) A method of viewing the double projection without changing this orientation.

(5) A method of measuring the stereoscopic model.

c. The methods used for fulfilling the above requirements are varied. In general, the more completely correct the solution, the more complicated, bulky,

costly, and slow the apparatus. Since it has the best average rating for the needs of the War Department, the multiplex was adopted after due consideration of the following factors: accuracy, simplicity, portability, speed of operation, ease of obtaining and training operators, manufacture in this country, original cost, and cost of operation. A detailed relative consideration of these factors is not necessary here.

5. MULTIPLEX METHOD OF MAPPING.—The multiplex uses photographs taken from a film camera complying with the requirements of a precision camera. These photographs are reduced in size and made into transparencies so that they may be used in projectors of small size. The projectors may be visualized as replicas of the taking camera, so placed along a horizontal bar as to be in the same relative positions occupied by the camera when each picture was taken. Rays from adjacent projectors intersect to form images in the same relative positions they occupied on the terrain. These images are viewed stereoscopically, measurements are made in the stereoscopic model, and the detail in the model is compiled into a conventional map on paper. Figure 8 shows a view of the multiplex equipment in operation.

6. APPLICATION.—The multiplex equipment is applicable to most mapping projects. It may be used for the preparation of maps in which the highest degree of accuracy is desired, or it may be used for reconnaissance mapping. Theoretically, the multiplex is capable of preparing maps at all scales and all contour intervals. Practically, this is limited by the ability to secure the necessary photography. Inability to secure photography at lower altitudes confines its use to scales smaller than about 1:3,000 and to contour intervals of 5 feet or greater. The maximum flight altitude of aircraft limits the smallest scale to approximately 1:30,000. Normal military missions require that the plotting be performed at a scale of about 1:20,000 or smaller, at which scale the contour interval possible is 50 feet or greater. While the multiplex equipment is most advantageously used in the preparation of complete topographic maps, it is also suitable for use in the preparation of planimetric maps.

7. AERIAL CAMERAS.—**a.** Certain aerial cameras, available in the Army Air Forces, are suitable for use with the multiplex equipment. The wide-angle multiplex is designed around the Metrogon wide-angle lens used in three different cameras having suitable characteristics for multiplex work, all of which have a nominal focal length of 6 inches and expose a negative 9 inches square. The T–5 camera is best suited to multiplex work because of its precision construction. However, both the K–3B and K–17 cameras, with the 6-inch wide-angle lens, have been used with the multiplex equipment with satisfactory results.

b. The original normal multiplex was designed for use with the central chamber of the T–3A camera, which exposes a negative 5.5 inches square and has a nominal focal length of 6 inches. The normal equipment may also be used with photography performed with the K–3B camera, which exposes a negative 7 by 9 inches and has a nominal focal length of 8¼ inches. Of those two cameras, the T–3A is generally more suitable.

8. PHOTOGRAPHY.—a. Photographs for use in multiplex mapping are exposed from the airplane with the axis of the camera vertical. To accomplish this, the camera is suspended in a mount over an opening provided in the bottom of the airplane. The mount provides manual means for leveling the camera so that its axis is vertical, and for rotating the camera about its axis so that the axis of the focal plane is kept parallel to the direction of travel of the airplane over the ground.

b. In order to prepare a topographic map of a given area with multiplex equipment, it is necessary that complete stereoscopic coverage of that area be made by aerial photographs. This means that when the photographic coverage is considered pair by pair within each flight, and flight by flight throughout the area, all parts of the terrain must be covered by photographs taken from at least two exposure stations. To accomplish this photography, it is usually specified that photographs overlap each other along the flight 60 percent, and that the side lap between adjacent flights be between 15 percent and 50 percent, depending upon the terrain, the accuracy of available flight maps, and the experience of the photographic crew. Crab and tilt can be tolerated to the extent that the photography will give complete stereoscopic coverage, but excessive crab and tilt will make the orientation of the multiplex models more difficult. The flight altitude should be held as constant as is consistent with good photographic flying and existing conditions. However, quite large variations in altitude may be accommodated with the multiplex equipment.

SECTION II

PRINCIPLES OF THE MULTIPLEX

9. GENERAL.—The basic theory underlying the operation of the multiplex is relatively simple. It is believed that an understanding of the principles of operation, while not essential, is an aid in the operation of this equipment. This section includes a brief explanation of the principles of multiplex operation with a brief discussion of the aerial camera and its relation to the equipment. In some instances, liberties are taken with the strict theory in order to present the material in a readily understood manner.

10. SOME OPTICAL CONSIDERATIONS.—**a.** The photography of terrain and the transformation of this photography into a projection which can be used in producing a topographical map is accomplished by using three optical instruments: the aerial camera, the multiplex reduction printer, and the multiplex projector. A brief consideration of some of the optical principles will be presented here. (More detailed explanations of optical theory will be found in any textbook on physics.)

b. A lens is a piece of glass or a combination of several pieces of glass which has been ground and polished to certain prescribed curvatures and thicknesses. Only the very simplest lenses consist of only one piece of glass or element. Most photographic lenses are compound, consisting of two or more elements. These elements may be made from different kinds of glass, may be ground with different radii of curvature, and may be cemented together or separated by an air space.

c. When light rays travel from air into glass or from glass into air at an angle to the surface other than normal, they are bent or refracted. The amount of their refraction varies with the type of glass and the angle of incidence to the surface. Thus, when parallel rays of light enter a well-designed and accurately constructed lens they are bent or refracted in such a way that they converge to a point.

d. The common optical formula expressing the relationship of image and object distance is:

$$1/f_1+1/f_2=1/F$$

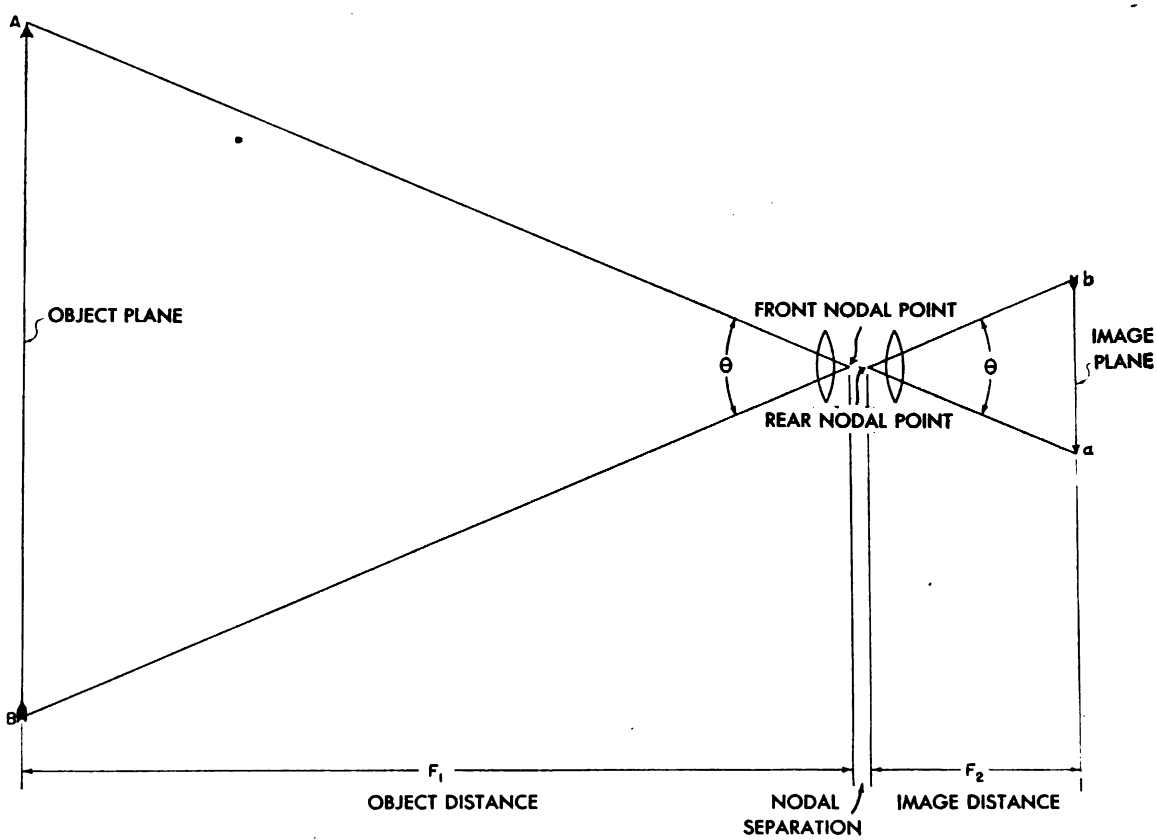

Figure 1.—Simple lens theory.

where f_2 is the image distance, f_1 is the object distance, and F is the focal length of the lens. The image and object distances for any condition of proper focus are known as conjugate distances. As the object distance approaches infinity, the image distance approaches equality with the focal length. The focal length of a lens is the image distance at which light from an object at infinity will be projected by the lens to form a clear, sharp image.

e. The physical measurement of the image and the object distance involves the measurement between the object and image planes and the lens. Since the lens has physical dimensions, it is necessary to know to what point on the lens such measurements should be made. Geometrical consideration of the action of light passing through the lens shows that for each lens there are two points called nodes. At these points the bundle of light rays emanating from the object is identical with the bundle projecting the image. The angular relationship between any two rays at the object node is identical with the angular relationship between corresponding rays at the image node. These points are referred to as the front nodal point and the rear nodal point, respectively. Figure 1 illustrates this aspect of the lens. In some lenses the nodal points are reversed so that the rear nodal point is closer to the object than the front nodal point. This is true in the 6-inch wide-angle Metrogon lens. The distance between the rear nodal point and the image plane is equal to the focal length

of the lens. The front (projection) node of the multiplex projector has important significance, as explained in paragraph 14*d*. In general considerations of the action of light rays, a lens can be replaced by a point which is usually called a perspective point.

f. In the multiplex projector the optical distance from the rear (diapositive) node to the plane of the diapositive emulsion or surface of the diapositive stage plate is known as the principal distance of the projector.

11. THE AERIAL CAMERA.—a. The principles of the aerial camera are, in essence, those of the amateur box camera with which everyone is familiar, except that additional features are provided in the aerial camera to adapt it to the peculiar requirements and the precision necessary for mapping from aerial photographs. The camera is a light-tight box having at one end a lens, and at the other, a fixture for holding a film coated with a light-sensitive emulsion. Like the box camera, the aerial camera is of the fixed focus type. A shutter and diaphragm are provided, as well as the necessary mechanisms for winding the film and tripping and winding the shutter.

b. The purpose of the aerial camera is simply to register on a plane, by means of the action of its lens and a light-sensitive film, a perspective projection of object points on the ground. Such action is illustrated in figure 2. In order that this perspective, which is registered on the negative, may be of value in making measurements, certain features of it must be known and must remain constant for the various exposures that are made. Toward this end, the various mechanical and constructional features of the camera are designed.

c. As in any camera or optical instrument, the lens is the most important part. The function of the lens is to project on a plane an image of an object. Every point of an object sends out rays of light in all directions. It is the function of the lens to project the rays which fall within the cone described by the angle of coverage of the lens to a common plane to form an image. As rays from each point in the object pass through the lens, they are refracted by the lens and converge to a single corresponding point in the image. A multiplicity of points in the object form a corresponding number of points in the image, and hence, the photograph. To simplify the explanation, the lens may be represented as a perspective point of projection. Its action is that of reproducing on its back side (toward the film) a cone of rays that is in all ways similar to the cone on the front side (toward the object). The accuracy with which a lens performs this action is one measure of its suitability in a mapping camera.

d. The focal plane is the plane in which the film emulsion lies during exposure. The lens is set in the camera at that distance from the focal plane which will give best overall definition of the negative. The film is held flat in the focal plane by a metal pressure plate behind the film which positions the film emulsion in the focal plane during exposure, and by a vacuum which is applied through holes in the pressure plate, thus pulling the film flat against the plate. Failure of the pressure plate to hold the film flat during exposure will disturb the true perspective relationship between images on the negative and

their corresponding objects. At the middle of the four edges of the focal plane are provided markers which are photographed on the negative at the instant of exposure. These are the fiducial marks and are placed so that lines joining opposite markers intersect at 90°, and so that this intersection is on the perpendicular from the lens to the focal plane. This point is the principal point and may thus be located on the negatives from the fiducial marks.

e. The shutter, together with the diaphragm stop, serves to regulate the amount of light which is permitted to reach the film. The diaphragm stop confines the light rays to certain portions of the lens. In general, the smaller the diaphragm stop the better the quality and sharpness of the resulting photograph. The diaphragm stop of an aerial camera is variable and can be adjusted by the photographer. Two general types of shutters are in use at the present time on Army Air Forces cameras: the between-the-lens and the focal plane types. Speed of the shutter can be varied by the photographer. The between-the-lens shutter is composed of a series of metal leaves arranged in the air space between the elements of the lens so that they can be opened or closed almost instantaneously. Exposure of all parts of the negative is therefore instantaneous. The focal plane shutter consists of a slit in a curtain which is passed in front of the film during exposure. Since all parts of the negative are not exposed at the same time, negatives taken with focal plane shutters are unsuitable for multiplex mapping. The movement of the airplane during the passage of the shutter across the film will destroy the true perspective relationships between the object and photographic image.

f. The film used for multiplex mapping work must have dimensional stability. Such a carrier for the emulsion is termed topographic base. The desired characteristics in the film base are achieved by proper manufacturing procedure and proper aging. Film which is not marked "topographic base" along its edges has not had the proper treatment during manufacture, and a negative made on this film will not be a true perspective view of the terrain photographed because of the irregular shrinkage and expansion to which ordinary film base is subject.

12. PERSPECTIVE ASPECTS OF PHOTOGRAPHS.—a. As illustrated in figure 2, a photograph is a perspective view of the terrain. A detailed analysis of this perspective is deemed unnecessary here, as complete information may be found in several textbooks* on photogrammetry. However, a brief consideration of a few aspects of photographic perspective may be helpful.

b. A truly vertical photograph of absolutely level terrain is a true-to-scale reproduction of that terrain. Except for the fact that natural and man-made features are not depicted by conventional signs, this photograph can be considered a planimetric map at a scale equal to $\frac{f}{H}$ where f equals the focal length of camera and H is the altitude of the camera station above the terrain. Since these ideal conditions of vertical photography and level terrain are never encountered in practice, analysis of the

**Collected Letters and Essays*, by O. von Gruber. *Engineering Application of Aerial and Terrestrial Photogrammetry*, by B. B. Talley. *Aerophotography and Aerosurveying*, by J. W. Bagley.

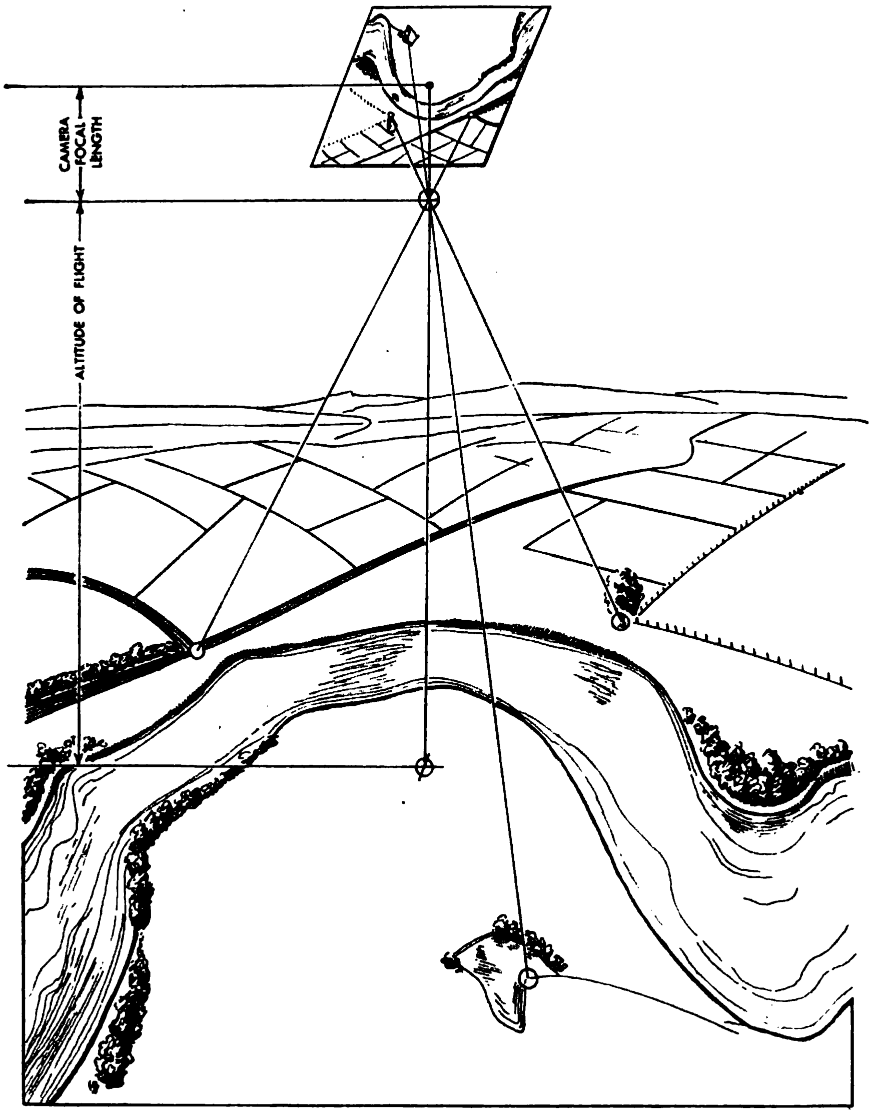

Figure 2.—Action of the aerial camera.

perspective view must be made in order to understand the effects of ground relief and the tilt and tip of the camera at the time of exposure on the images recorded on the photograph.

c. Figure 3 illustrates the effect which relief of the terrain produces in the perspective view, as registered on both a vertical and a tilted photograph. On the vertical photograph, the image *a–b* which represents a tall object *A–B* lies on a line which is radial from the plumb point. In the tilted photograph this object is represented by the image *a′–b′*. Because of the constantly varying scale of the tilted photograph, the distance *a′–b′* does not equal the distance *a–b* on the untilted photograph.

d. When photographs are taken of the same terrain from two different exposure stations, the perspective views will be different since each photograph is taken from a different standpoint. This is illustrated in figure 4. Every point in the overlapping area is thus seen in two perspectives. When over-

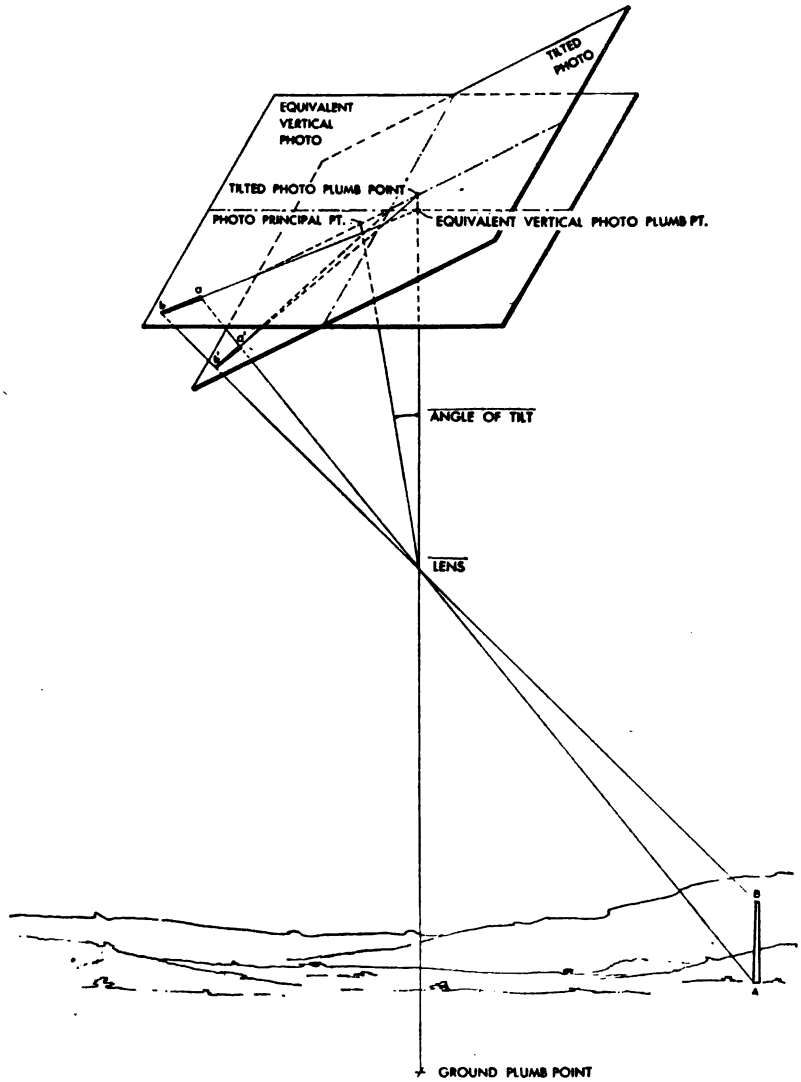

Figure 3.—Distortion of images due to effect of tilt and relief in an aerial photograph.

lapping photographs are oriented in the multiplex projectors or in a stereoscope, the two perspective views are relatively oriented to each other so that each eye of the operator views a single perspective. These two separate perspective views are combined in the mind of the operator to produce the phenomenon of depth perception.

13. CAMERA-PRINTER-PROJECTOR RELATIONSHIP.—a. The theory of the multiplex process is based on the reconstitution in miniature of the terrain photographed by the camera. This is accomplished by the projection of overlapping diapositives (reduced positives of negatives exposed in camera) in complementary colors and the viewing of these projections with like complementary filters over the eyes of the operator. In order that the resulting projections from the multiplex projectors will form a true scaled model of the terrain, the angular relationships between light rays coming from objects on the ground,

which existed at the time of exposure of the negative in the camera, must also exist in the projection from the multiplex projectors in reconstituting the model. Therefore, the multiplex reduction printer which reduces the negative to diapositive size and the multiplex projectors must be fabricated with precision, both mechanically and optically.

b. Up to this point it has been assumed that the lens in the camera will reproduce exactly on the side toward the negative the cone of rays which entered from the side of the terrain. Such a lens would be said to have no distortion. The 6-inch Metrogon lens, used in the Army Air Forces wide-angle cameras, is no such ideal lens. In fact, the distortion present in this lens is considerable. Because of the adverse effect which this distortion would have in the multiplex model, the lens in the wide-angle reduction printer has distortion characteristics which compensate for the distortion in the camera lens. In this way, the diapositive produced in the reduction printer is relatively free from distortion; that is, when the diapositive is reprojected in a projector lens which is free from distortion, the light rays have the same angular relationship as the light rays subtended by the terrain at the lens of the camera when the negative was exposed. Since distortion in lenses of cameras used in connection with the normal multiplex equipment is very small, the lens in normal reduction printers is free from distortion. Both wide-angle and normal projectors have lenses as free from distortion as possible, so that the correct angular relationships may be maintained.

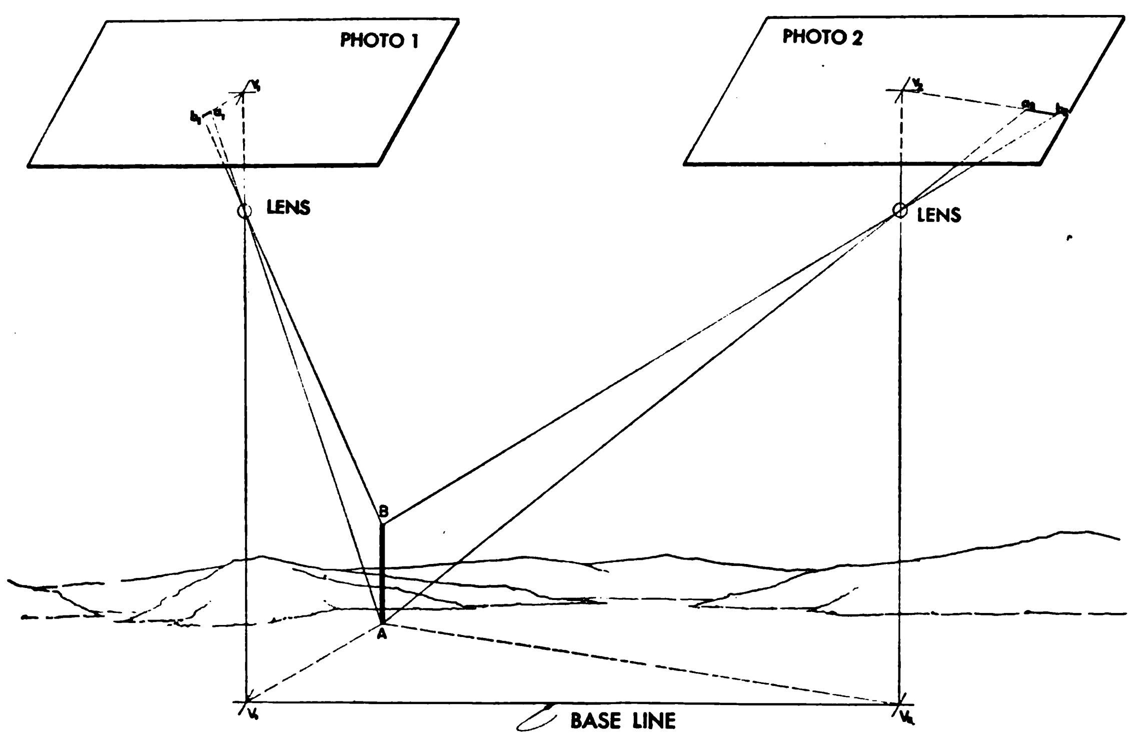

Figure 4.—The effect of relief in successive photographs.

c. To assure further that the angular relationships in the original cone of rays are correctly duplicated in the projection, the reduction ratio of the reduction printer must be equal to the ratio of the principal distance of the projector divided by the focal length of the camera. In the manufacturer of multiplex equipment, the principal distances of the projectors are held within a tolerance small enough to assume that all wide-angle projectors have a constant principal distance of 28.18 mm and normal projectors a principal distance of 46.04 mm. Camera focal lengths are not as constant and will vary within a small range. In order to compensate for varying camera focal length, the wide-angle reduction printer has provision for changing the reduction factor. This change is accomplished by changing the conjugate distances in the printers. Figure 5 shows a schematic diagram of the ideal camera-printer-projector relationship and the constant factors which must be maintained. The diapositive stage and the negative plane in the reduction printer must be parallel in order to obtain a true reduction. There is no provision for varying the reduction ratio of normal reduction printers, with the result that a slight error is introduced when a camera is used having a focal length which departs considerably from the focal length of the camera for which the reduction printer was designed.

14. PRINCIPLE OF THE MODEL.—a. As discussed in paragraph 13, the diapositive has been made in such a way that when it is placed and correctly oriented in the multiplex projectors, the projection which is formed duplicates in miniature the cone of rays originally reflected from the ground to

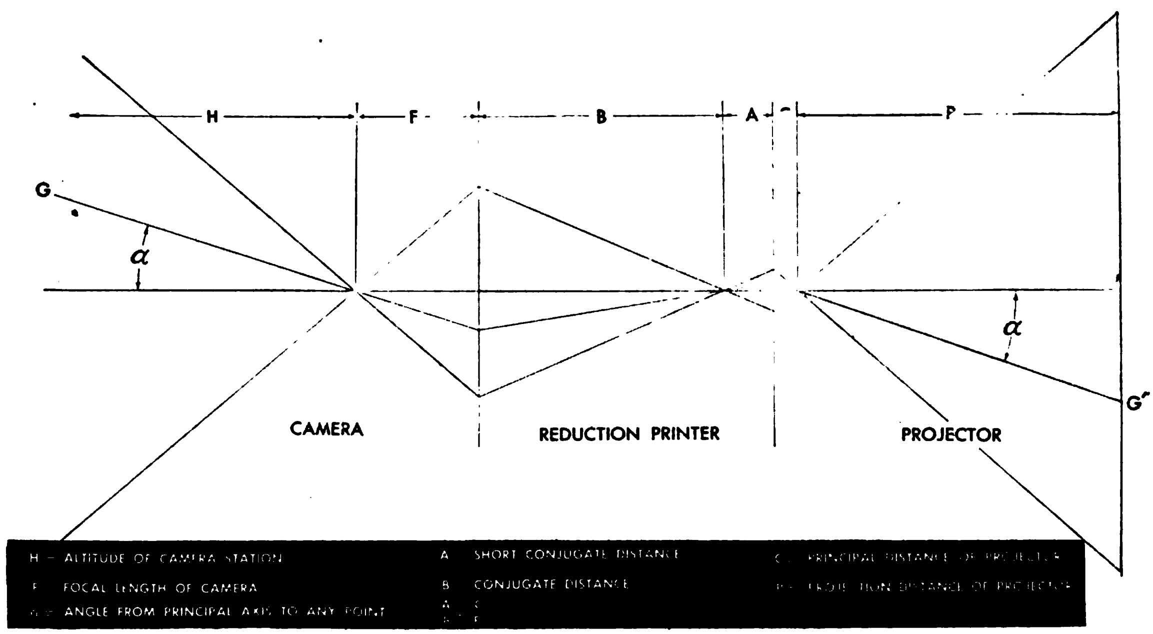

Figure 5.—Schematic diagram showing ideal camera-printer-projector relationship.

the aerial camera, each ray being in correct relationship to every other ray in the cone. When two such projections are oriented together a multiplex model results.

b. In order to view this multiplex model, use is made of filters of complementary colors. When two colors are truly complementary, no light will be transmitted through the combination of the two colors. In multiplex projection, the two complementary colors used are red and blue-green. If the left projector is equipped with a red filter, and the right one with a blue-green filter, a red filter is worn over the left eye of the operator, and a blue-green filter over the right eye; he will see only the projection from the left projector with his left eye and from the right projector with his right eye. This, in effect, means that the left eye is at the first camera station viewing the perspective as was recorded on the film at that station, while the right eye is at the second camera station viewing the second perspective. When the multiplex model is correctly oriented, the mind of the operator assembles these two perspective views so that the operator sees one view depicting a small relief model of that part of the terrain which was photographed. The relief model shows depressions in the valleys and peaks at the hill-tops and elevated portions of the model. Trees and buildings will appear to stand upright.

c. The model is formed when the projectors are so oriented that all corresponding rays from each of the two projectors intersect in space. These ray intersections are not all in the same horizontal plane except for those points having the same elevation above datum. But a series of horizontal planes, passing through the model and spaced at infinitely small distances apart, contain all the intersections of corresponding rays of a correctly oriented model. The map datum is parallel to the table on which the apparatus rests, and the model as a whole may be tilted with respect to this datum without disturbing the relative positions of the projectors. This tilting of the model as a whole is termed horizontalization. In a correctly horizontalized model, horizontal planes cutting the model at vertical spacings equal to the contour interval describe contours at their intersections with the model.

d. The individual projectors of a correctly oriented model assume the same relative positions that the aerial camera had during exposure. Figure 6 illustrates schematically the basic theory of the multiplex. The spacing between projectors, called the "base," is, in miniature, equivalent to the air base between the corresponding exposures. This "base" may be resolved along the three usual coordinate axes into its three components, bx, by, and bz, or base components of X, Y, and Z. Each projector is rotated about its X axis, called "tilt", its Y axis, called "tip," and its Z axis, called "swing," the identical amount that the aerial camera was misalined at the instant of exposure. The distance between the front (projection) node of the projector and a plane passing through the model corresponding to sea level datum is equivalent to the altitude of the airplane above sea level at the scale of the multiplex model at the instant of exposure.

e. Because of the limitation in the usable projection distance of the multiplex projector, the plotting scale, or the scale of the multiplex model is limited for any given flight altitude. Since the

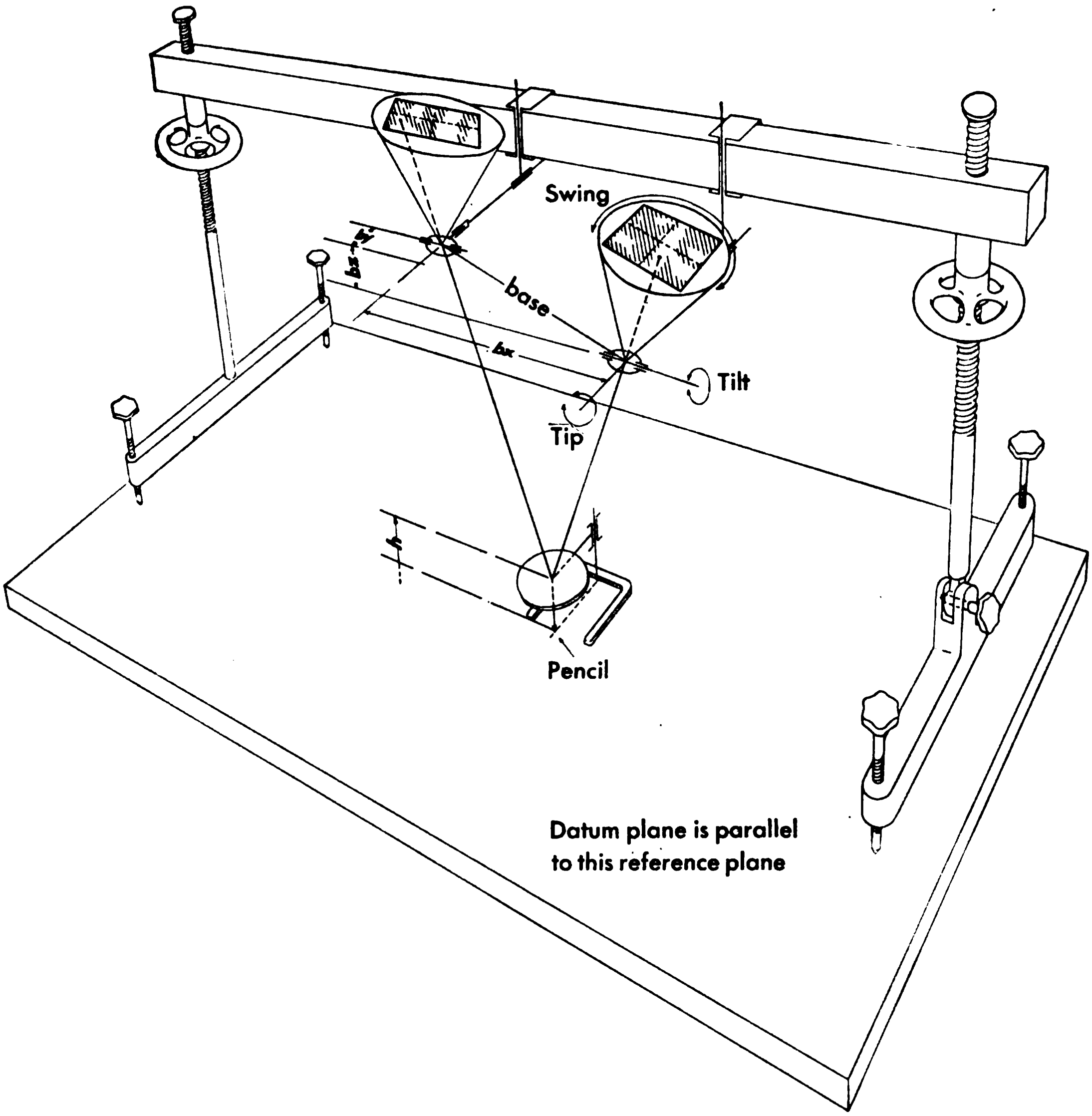

Figure 6.—Theory of the multiplex.

plotting scale is the ratio of a distance on the plot to a corresponding distance on the ground, it is usually expressed as $1/D$, in which a unit on the plot is expressed as 1 and the same unit on the ground as D. This ratio is called the "representative fraction." From the symmetry of figure 5, it is seen that—

$$\frac{1}{D}=\frac{P}{C}\times\frac{A}{B}\times\frac{F}{H}$$

where P = projection distance
C = principal distance of projector
A/B = reduction ratio of printer
F = focal length of camera
H = flight altitude

$$\frac{A}{B}=\frac{C}{F}$$

$$\frac{1}{D}=\frac{P}{H}$$

The optimum projection distance of the multiplex projector is 360 mm, but the usable range in projection distance is from a minimum of 270 mm to a maxi-

mum of 450 mm. The chart in figure 7 presents a quick means of determining the correct plotting scale for any given flight altitude. In this determination, altitude above the mean level of the terrain photographed is used.

15. MEASUREMENTS IN THE MODEL.—a. The multiplex model which is formed by correctly oriented projectors is a portion of the earth's surface in miniature and is true to scale. Measurements can be made either horizontally or vertically in such a model. Both types of measurements are made by means of the tracing table shown schematically in figure 6.

b. To convert the multiplex mode into a conventional map on paper, a system for measuring the model is necessary. Use is made of a "floating mark." This is a point on the flat white surface of the tracing table, visible to both eyes through the filter spectacles. When the eyes are focused on the surface of the model, a point beyond the depth of focus of the eyes does not fuse and therefore appears double, one image for each eye. As the point is brought closer to the model the two images fuse into one, but appear to be below (or above) the surface of the model. As the motion continues, the point eventually appears to lie on

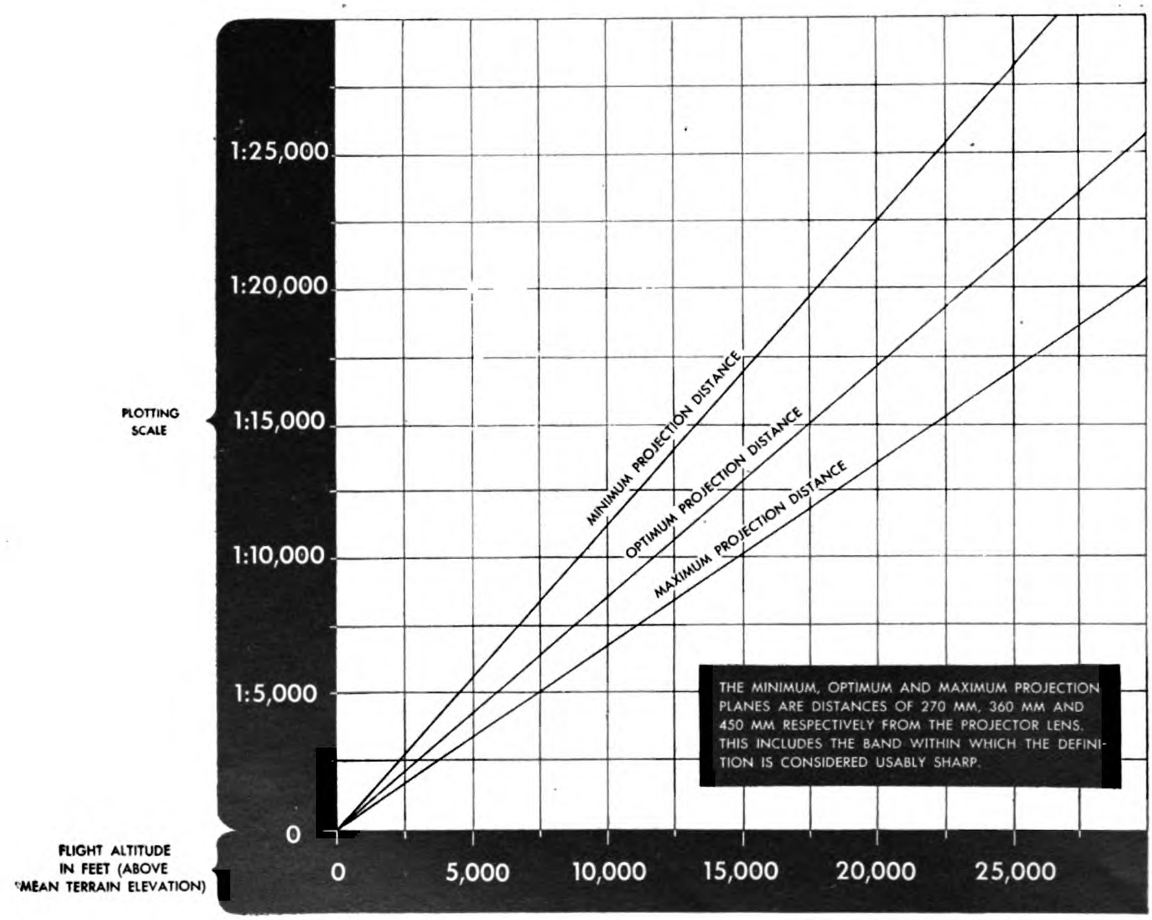

Figure 7.—Multiplex plotting scale and flight altitude.

the surface of the model. How closely this condition can be obtained depends on the acuity of the depth perception of the individual and the character of the model (sharp, clear contrasts as against flat, indefinite terrain). Directly below the floating mark is a pencil. This pencil records the orthographic projection of the floating mark, and hence any point in contact with the floating mark may be recorded in its true map position.

c. Horizontal scaling is accomplished by plotting with the pencil of the tracing table the points in the model between which it is desired to scale. This distance is then measured by a scale and compared with the correct ground distance reduced to the plotting scale of the model. A somewhat simpler method of scaling is the shifting under the tracing table of the plotting sheet, upon which known positions have been plotted. Adjustments to the model are then made, and the sheet is shifted and reoriented until all points are correctly positioned.

d. When the model is correctly scaled horizontally, it is also correctly scaled vertically. Elevations of points in the model may then be read by setting the floating mark on the point and reading the scale attached to the platen of the tracing table. If a contour is to be drawn, the floating mark is set for a definite height, brought in contact with the surface of the model, and moved over the model, always maintaining contact. The orthographic projection of this path is thus plotted continuously on a suitable medium on the table. For plotting planimetry, lines of planimetric detail are followed, with the floating mark always in contact with the detail.

SECTION III

MULTIPLEX EQUIPMENT

16. GENERAL.—Two types of multiplex equipment are now in use, the normal and the wide-angle. Since the normal equipment is rapidly being replaced by wide-angle equipment, emphasis will be placed on description of the wide-angle equipment, with only a brief description of the normal equipment.

17. LOCATION.—**a.** Since multiplex mapping consists of precise measurements made with delicate instruments, it is important to select a location in which this work can be accomplished with the maximum efficiency. The primary requirement for location is maximum freedom from vibration; a ground-floor location with a solid foundation and concrete floor, away from vibration caused by traffic and machinery, is excellent.

b. A room approximately 10 by 12 feet, with proper facilities for ventilation, should be provided for each multiplex unit. Air-conditioning to control dimensional changes of the map compilation medium is desirable. When the suction type cooling unit is used, if possible, provision should be made for installing it outside the multiplex rooms (on the roof, in the rear of buildings, etc.) in order to eliminate a large proportion of the noise and vibration. Paragraph 23*d* describes the installation of this cooling unit in detail.

c. Electrical outlets are necessary for the voltage regulator, the cooling unit, a table lamp, an overhead light, a ventilating fan (if used), and a circulating fan. Switches should be located conveniently for use by the operator.

d. The lay-out for a multiplex mapping organization varies with the facilities available. It includes a sufficient number of multiplex rooms to utilize the equipment, one or more darkrooms, one or more drafting rooms, a stock room, a repair room, filing space, and offices as required. Sufficient darkroom space, equipped with hot and cold water and sewer connections, should be provided for the making of diapositives and contact prints. The drafting room or rooms should be of sufficient size to provide for drafting, editing, plotting, and lay-out work.

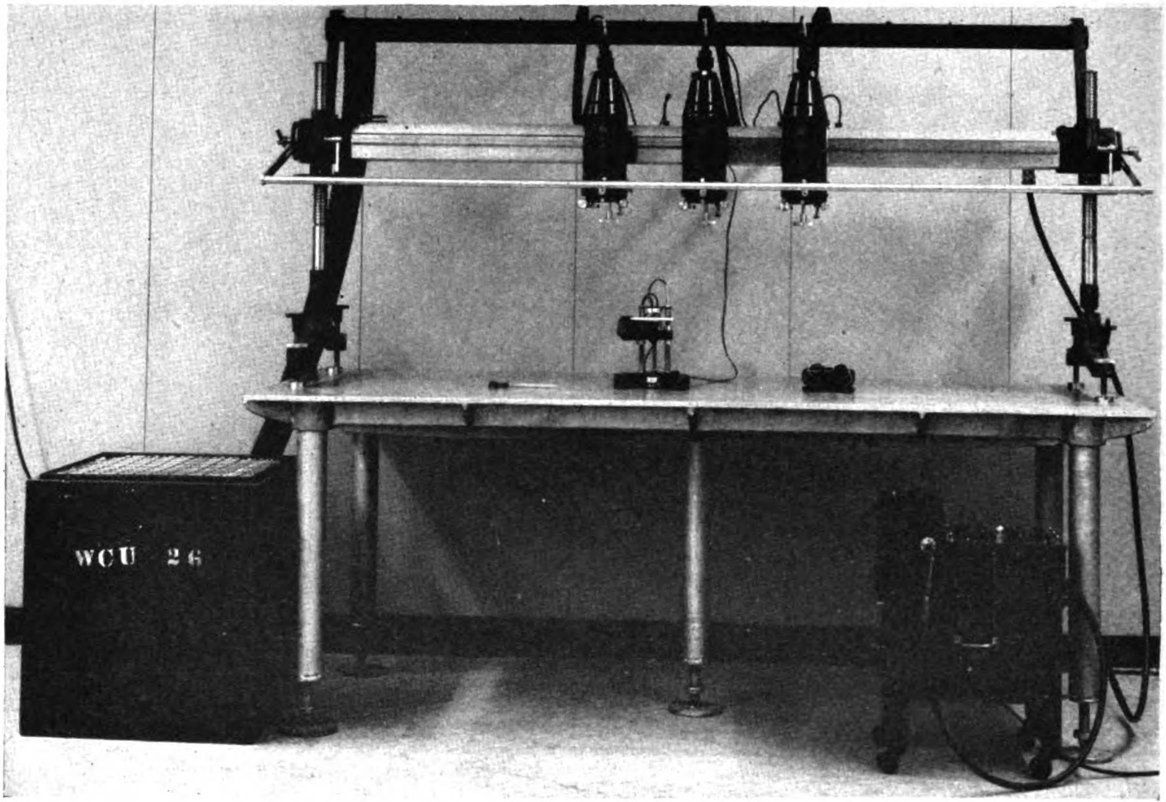

Figure 8.—Multiplex unit set up ready for operation.

18. MULTIPLEX UNITS.—a. A multiplex unit for compiling detail on the map sheet consists of the following items of equipment:

(1) 1 table.
(2) 1 frame.
(3) 1 cooling unit.
(4) 1 voltage regulator.
(5) 2 or more projectors with filters.
(6) 1 tracing table.
(7) 1 pair of spectacles.

These items of equipment are shown ready for operation in figure 8.

b. A multiplex unit for long extensions of control consists of the following items of equipment:

(1) 2 tables.
(2) 1 center support.
(3) 1 double frame.
(4) 2 cooling units.
(5) 2 voltage regulators.
(6) Projectors (number required for extension).
(7) 1 tracing table.
(8) 1 pair of spectacles.

Extension of control up to a distance of 1,600 mm or 5¼ feet may be accomplished with the multiplex unit listed in *a* above when sufficient projectors are utilized to span the bar.

c. In addition to the items listed in *a* and *b* above, the following equipment is part of the multiplex set:

(1) Reduction printers.
(2) Projector level.
(3) Height gage.
(4) Lead sharpener.

19. TABLE.—a. Since the multiplex table is the datum upon which the map

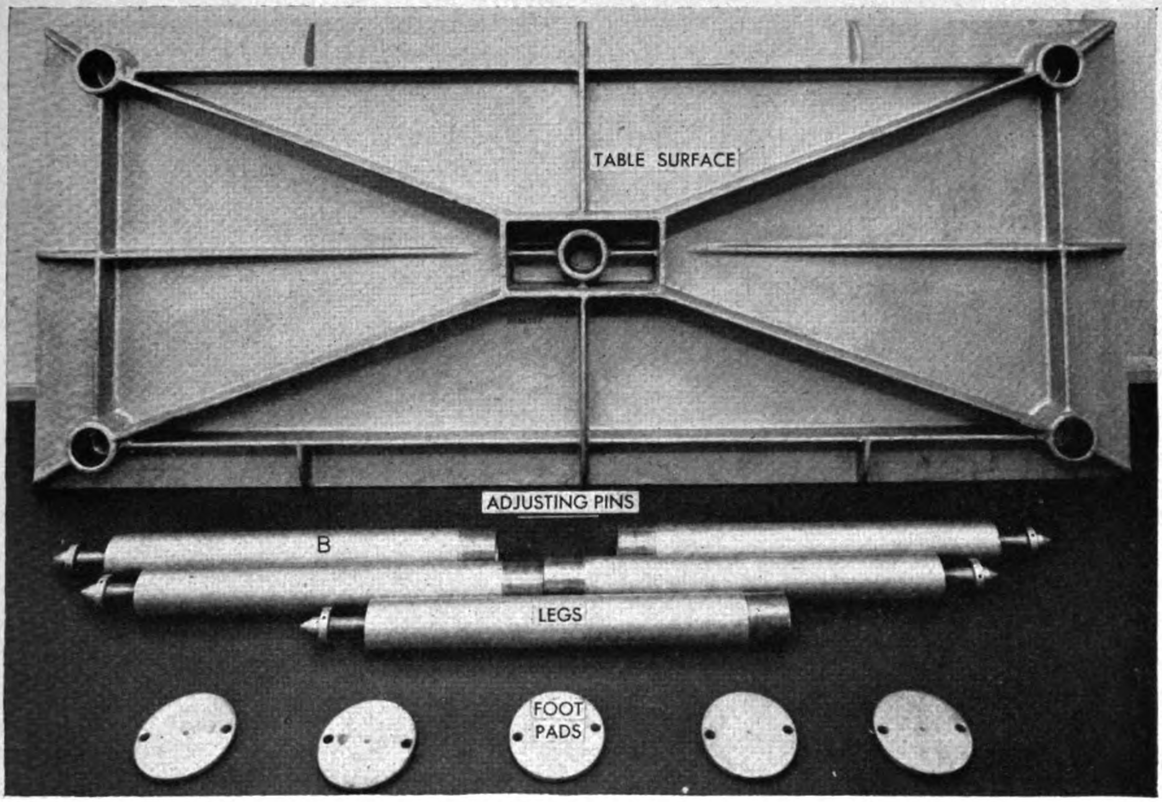

Figure 9.—Table dismounted.

is drawn, it is extremely important that the surface be a true plane. This surface supports the medium upon which the map is compiled. The tracing table is moved over this medium while the detail from the stereoscopic model is traced out. Any table of sturdy construction whose surface, whether metal, wood, or slate, is flat and true within ±0.001 inch of any 12-inch length, can be used. The standard table furnished with the equipment is shown dismounted, with the various parts displayed, in figure 9. The completely assembled table is illustrated in figure 8. This table (fig. 9) is made of reinforced cast aluminum, supported by five detachable legs. Each leg is marked with a number corresponding to the number of the socket in the table top into which it makes a sliding fit. The table surface is 3 feet by 7 feet, and when assembled the table is approximately 32 inches high. The table surface can be leveled by adjusting the feet which screw into the bases of the legs. Adjusting pins are provided for this purpose. Footpads with conical depressions for the feet are furnished.

b. Care must be taken to prevent warpage of the table top due to maladjustment of the feet. The level of the table should be checked periodically and the legs readjusted accordingly. When provided, the locking nuts on each table leg should be secured after leveling (not shown in fig. 9). Care must also be taken to prevent marring the surface.

20. FRAME.—**a.** The frame, consisting essentially of two upright supports and a horizontal bar, affords means of suspending the projectors in space above the datum plane or table, thereby reconstituting in miniature the camera stations above the earth's datum. By means of certain movements on this frame, one or more models may be tilted as a whole about an axis parallel to the bar, or tipped about an axis perpendicular to the bar, thus simplifying the task of horizontalizing the spatial models. The frame also carries the electrical connections for the projectors and the cooling header and hose connections for cooling the projectors. The foot screws on each support are 20 inches apart; the supports are 77½ inches apart. The overall height, including the cooling header, can be varied from 27 to 41 inches.

b. Figure 10 shows the wide-angle frame dismounted and the various parts displayed. The completely assembled wide-angle frame is shown in figure 8. The normal frame is of the same design as the wide-angle frame, differing only in the diameter of the support tube which is larger in the wide-angle frame in order to support the additional weight of the wide-angle projectors. In figure 10 each of the upright supports (A and B) consists of a base supported by two foot screws (9) held in place by means of the stop rings (8). When the frame is erected, the foot screws rest on the footpads, (22). The base supports the elevating screw (7), an acme-threaded screw 15 inches long, upon which runs a handwheel (3). Support (A) is a rigid piece and is the left-hand support for the frame; support (B) has a pin-connected joint (13), which can be made rigid by clamp (10), and is the right-hand support for the frame. The support brackets (6) of the tube and the base bar assembly (C) slide over the elevating screws in a keyway (12). This base bar assembly consists of a tube (14) faced with a base bar (15) between the two support brackets. Two level vials (11) at right angles are used for leveling the bar. When a projector is hung on the base bar, it can be moved along the bar by the pinion of the projector engaging with the rack (16) of the base bar. Attached to the tube (14) is a channel (17) which contains the wiring and electrical outlets for the projectors. There are 12 outlets numbered from 1 to 10, with two marked O (T and L on some frames). The outlets, numbered 1 to 10, serve the projectors, and by means of the voltage regulator (see par. 24) the voltage from these outlets can be varied. The other two outlets give a constant voltage of 20 volts when the plug type regulator is used and 21.5 volts when the dial type regulator is used, and are the power source for the tracing table. On the under side of one end of the channel is a 13-prong male plug for connection to the voltage regulator. Mounted on top of the support brackets and freely suspended is a 2½-inch tube (18) which serves as the cooling header. The header has eleven ¾-inch nipples (20), each equipped with a sliding valve operated by the knob (19.) Nine ¾-inch hoses (29), 38 inches long, are furnished with each frame for connecting the nipple to the projector. A 3-inch hose (28), 6 feet long, is furnished to make the connection between the 3-inch nipple (21) located at one end of the tube and the cooling unit. The 3-inch nipple, which is fastened to the tube by four bolts, can be placed at either end of the tube

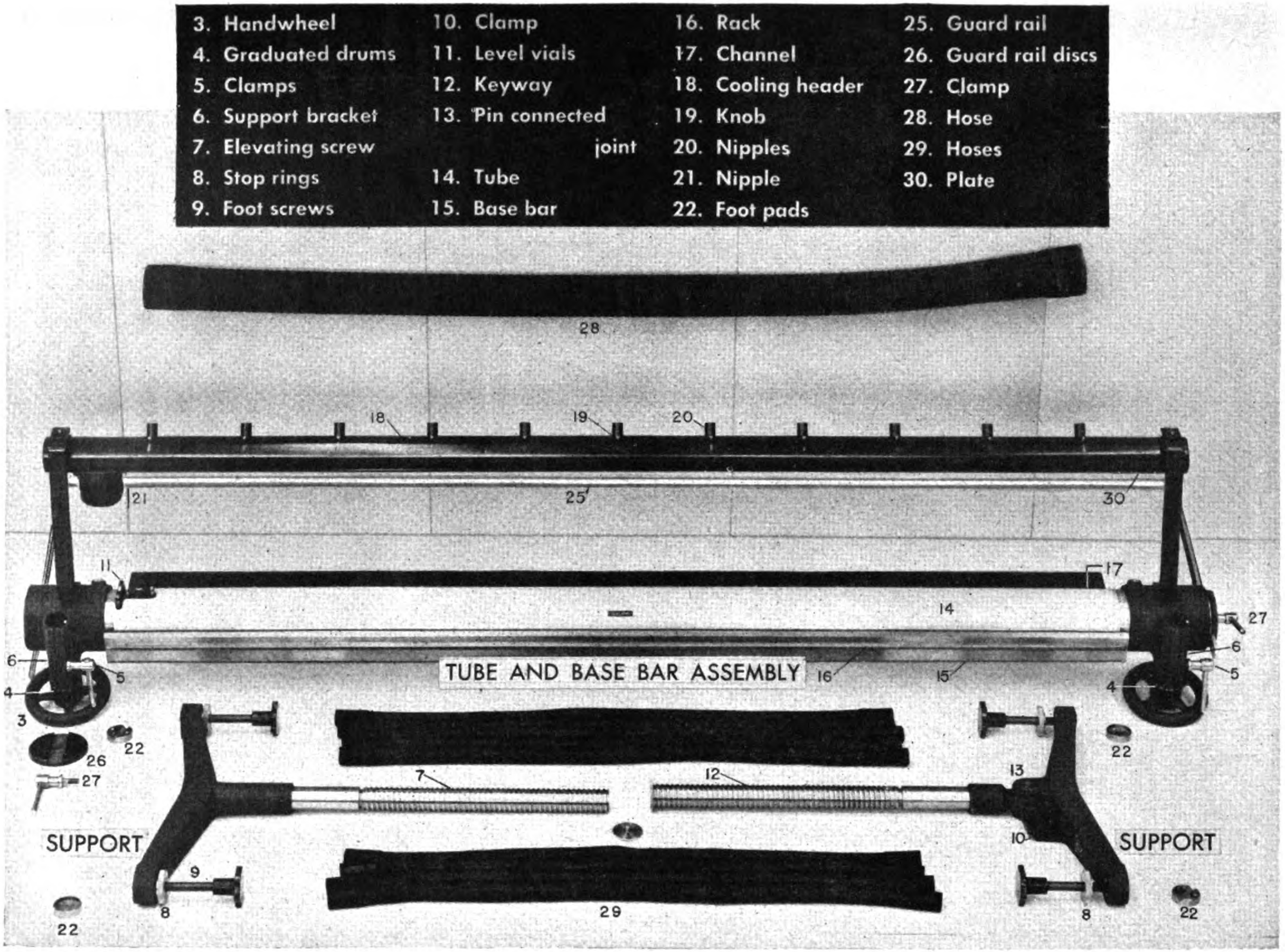

Figure 10.—Frame dismounted.

and is interchangeable with the plate (30). To remove the nipple or plate, screw off the cap at the end of the cooling header. While removing the screws which hold the nipple or plate, the nuts inside the tube must be held by means of the spanner wrench supplied with the frame. The guard rail (25), which is held to the support bracket (6) by the guard rail disks (26) and the clamp (27), serves to protect the projectors from being accidentally disturbed.

c. Before moving the handwheels or foot screws to change the position of the bar, the stop rings (8) must be raised and the clamps (5) and clamp (10) loosened to prevent strains in the bar. To change the level of the bar longitudinally (tip), raise or lower the handwheels. It is usually desirable to raise one and lower the other, so as to maintain the mean height of the bar. By means of the graduated drums (4) it is possible to raise or lower each end an equal amount. There are two methods of altering the level of the frame transverse to the direction of the bar. During the tilting process, the axis of rotation of the bar should be parallel to the bar. This condition is brought about by raising one foot screw and lowering the other foot screw of support (A) an equal amount, or by raising or lowering both front foot screws or both rear foot screws an equal amount. In the first case, a line joining the pin-connected joint (13) and a point midway between the base of the foot screws of the left support is the axis of rotation. In the second case, the axis of rotation is a line either joining the bases of the two rear foot screws or the two at the front, as the case might be, and the pin joint prevents any strain that would have been introduced in the frame if the foot screws were turned unequal amounts. After the proper position of the bar is attained, lower the rings (8) and tighten the clamps (5) and (10).

21. CENTER SUPPORT.—a. The center support furnishes the middle rest for the double frame; by means of this support and the double frame, a continuous frame is formed. The center support (fig. 11) consists of a base (A), a column (B), an arm (C), and an adapter (D). When assembled, it is 73 inches high.

b. The column (B) slides into the base (A) and is held in position by means of Allen head setscrews. The base may be fastened to the floor. The cap (1) is removed and the arm (C) slides over the top of the column. The arm is held in the desired position by means of a clamping bolt (7) on the back side of the arm. The arm extends 18 inches and may be swung about the column. The adapter (D) consists of a base bar and rack (2) and a tube (3) for joining with the double frame. The connection between the adapter and the tube of the frame is locked by means of a lock screw on each side of the adapter. A seat for the cooling header bracket is provided on each side of the adapter. The adapter is supported on the arm by means of a screw (4), two nuts (5), and a universal joint (6). Rough adjustment for position is made by sliding the arm (C) vertically along column (B) and locking in place with the clamping bolt. More precise adjustment is made by means of the nuts (5). When the center support is assembled, the cap (1) is replaced. A short length of rod is provided for joining the guardrails of the two frames to form a single long guardrail. A special wrench is fur-

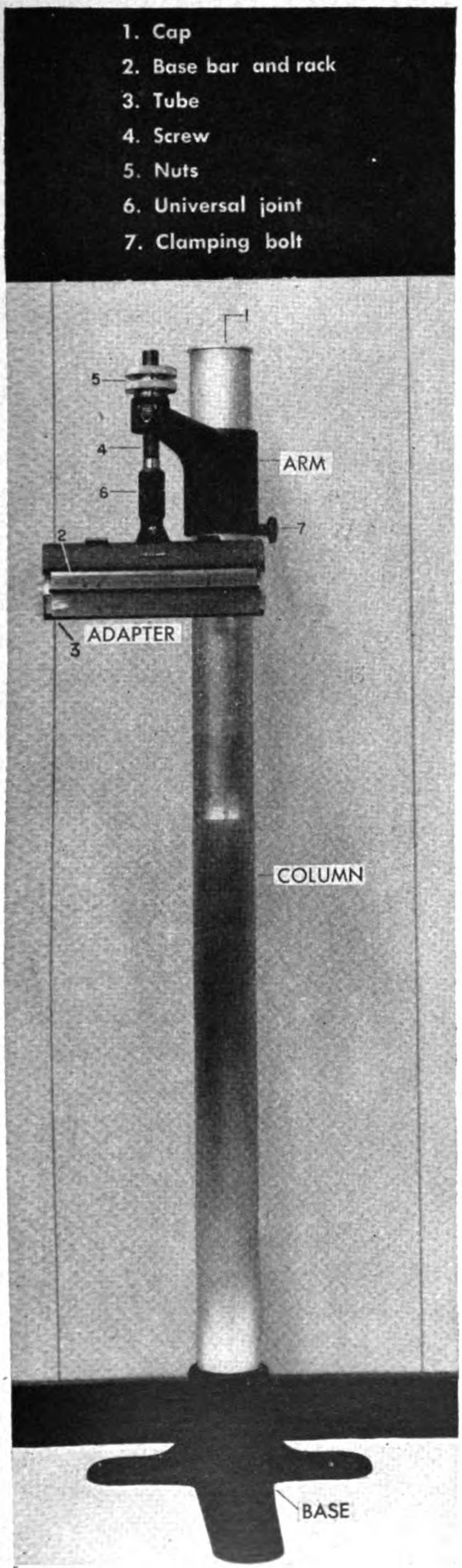

Figure 11.—Center support.

nished with the center support which is used to remove the plug in the end of the tube of the frame; removal is necessary in order to attach the frame to the center support.

c. As described in paragraph 22, the center support is fitted to one right-hand frame and one left-hand frame. These frames are not interchangeable. Therefore, the numbers of those frames which fit the center support are engraved on the base bar of the adapter.

22. DOUBLE FRAME.—a. The double frame consists of one left-hand frame and one right-hand frame which, together with the center support, form a continuous frame. Each frame is identical with that described in paragraph 20, and is furnished complete so that each could be used as a single frame. The left-hand frame, center support, and right-hand frame form a unit which has been fitted together at the factory. An illustration of the double frame and center support is shown in figure 12.

b. Two voltage regulators and two cooling units are required with the double frame. The electrical system and cooling system of the right- and left-hand frames remain independent. The 3-inch nipples for the connection to the cooling unit are usually placed at the two ends of the double frame for convenience. Electrical connections to the frames are also provided at the two ends of those frames most recently procured.

c. To tip the double frame without causing any strain in the bar it is necessary to raise one end and lower the other at the same time, leaving the nuts on the center support locked in place. Since this is practically impossible, it is advisable to raise one end a short

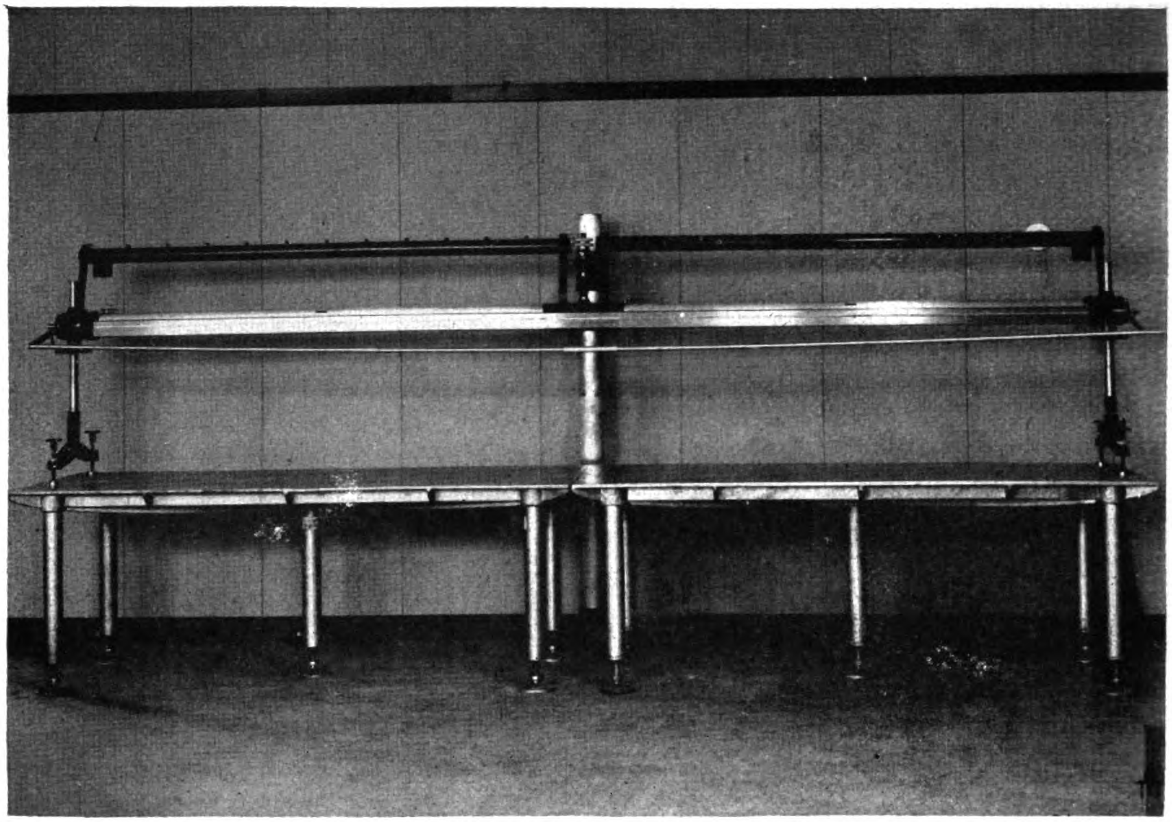

Figure 12.—Wide angle double frame.

distance, then lower the other an equal distance, repeating the procedure until the desired orientation is reached.

23. COOLING UNIT.—a. In order to dissipate the heat produced by the 100-watt projector bulbs, a cooling unit is supplied with each frame. Two types are used, one producing the cooling effect by suction and the second by blowing; the latter is supplied on latest procurement.

b. The suction-type cooling unit (fig. 13) is equipped with a 3-inch olive-drab sleeve on the suction side (1) for connection with the 3-inch hose, which is supplied as part of the frame. The discharge pipe (2) is threaded on the inside for a 2½-inch pipe connection. The blower is directly connected to a ¾-hp, 1-phase, 60-cycle, 110/220-volt motor which operates at 3,450 rpm. An off-and-on switch is located at (3). The motor should be operated on 220 volts if possible. The unit occupies a space 20½ inches long, 19 inches wide, and 22½ inches high, and is bolted to a base 21 by 10 by 3½ inches. This base slides into and forms the bottom of the packing case.

c. The blowing type of cooling unit produces its cooling effect by forcing air through the cooling header of the frame and the projectors. It is operated mounted in its case (fig. 14). A zigzag filtering unit fits over the top opening. The incoming air passes through the filter into the suction intake (1) of the

blower. The discharge pipe (2) is fitted in the side of the case for connection with the 3-inch olive-drab hose for joining the cooling header of the frame. The opening may be covered by a plate (4) when the unit is not in use. The blower is directly connected to a ⅓-hp, 1-phase, 60-cycle, 110/220-volt motor which operates at 3,450 rpm. The plug for the electrical connection and an off-and-on switch are located in the recess (3). The wooden top is fastened to the case by four clamps (5). Inside the top are two flat compartments for holding two spare filtering units and 20 feet of electrical cable for connection from the unit to the power outlet. Rock wool is used as insulation between the wooden case and the galvanized-iron liner. A few blowers in service are

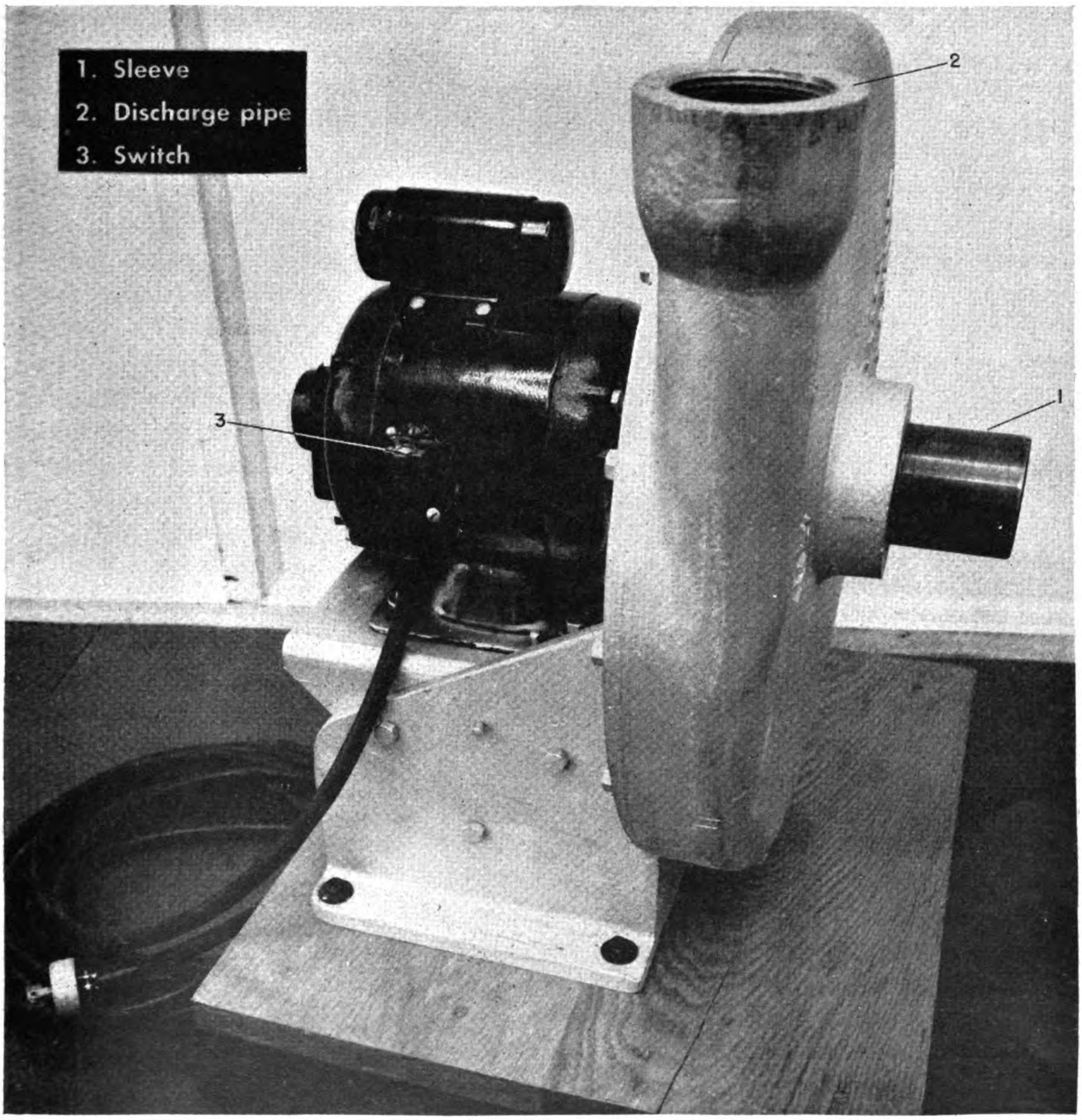

Figure 13.—Suction-type cooling unit.

not equipped with the filtering unit. The blowers are removed from their cases during operation.

d. In order to lessen the noise and decrease vibration, the possibilities of locating the suction-type cooling unit either on the ground outside the building or on the roof should be considered in selecting the site for the multiplex rooms. To house the units, there should be provided a waterproof shelter so constructed that the motor is ventilated and easily accessible for servicing. Piping connections from the multiplex

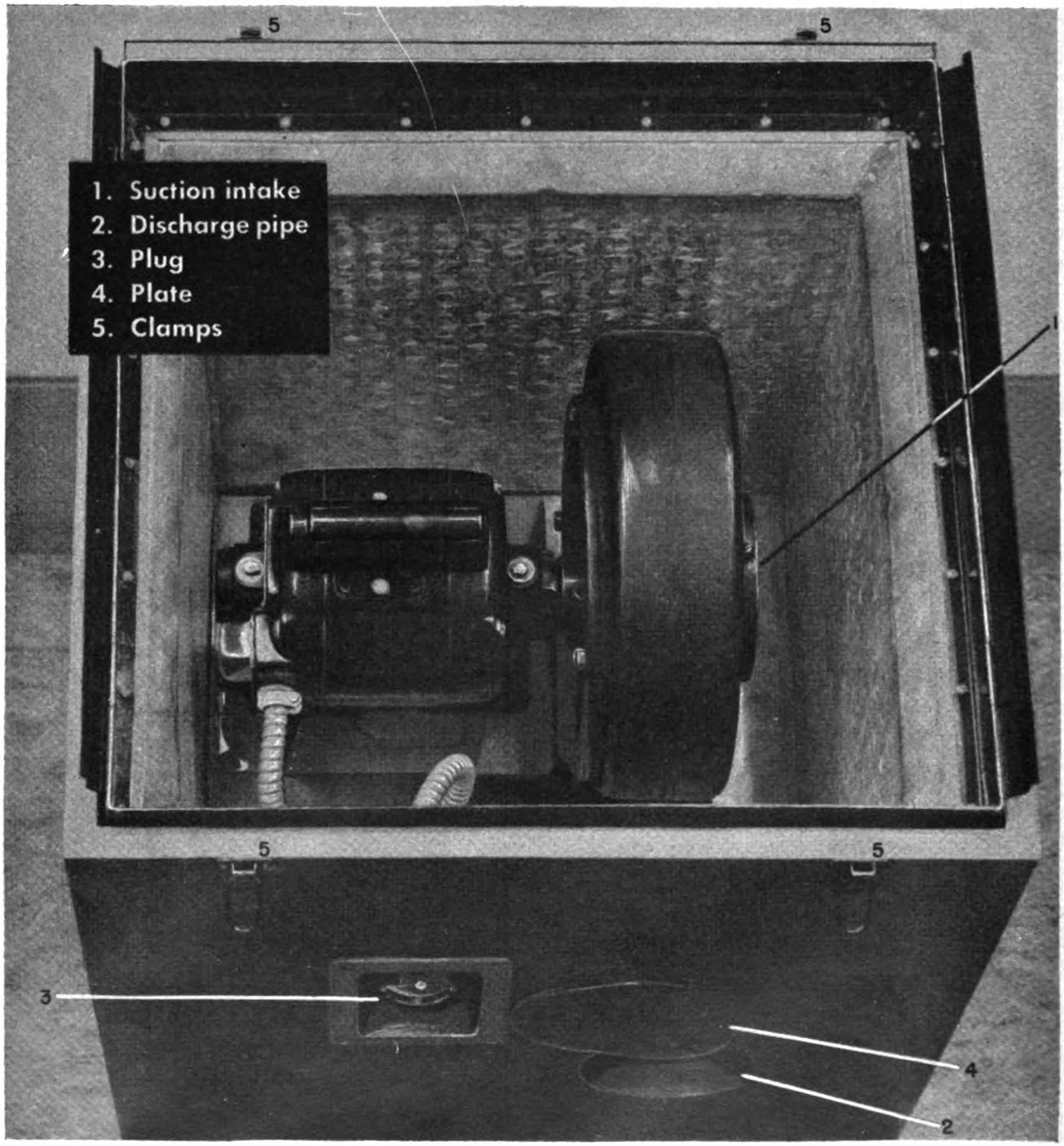

Figure 14.—Blower-type cooling unit.

rooms to the blower can be galvanized iron or ordinary black pipe, and should be kept as short and straight as possible. Care should be taken that all joints and seams are airtight. If it is found impracticable to install the cooling units outside the multiplex rooms, the noise and vibration can be reduced by exhausting the air into a muffler. A satisfactory muffler can be constructed by putting a series of baffles in a box constructed of celotex or a similar material. Vibration can be reduced by mounting the blower on sponge rubber. The 3-inch (diameter) hose should be placed so that it does not touch the multiplex table or frame, as vibration in the hose would be transmitted to the projectors and cause parallax in the multiplex models.

e. The installation of the blowing-type cooling unit presents no problem, since the noise of the blower is not objectionable. This blower can be placed in any convenient location where it can be connected to the cooling header of the frame.

f. The ¾-hp motor is equipped with ball bearings packed with grease. The old grease should be cleaned out once a year and the bearings repacked. The ⅓-hp motor has wool-packed bearings which should be oiled every two weeks.

24. VOLTAGE REGULATOR.—a. The projectors and tracing table are operated on 20 volts. In order to reduce the line voltage to 20 volts and also provide means for regulating the intensity of illumination of the various projectors, a voltage regulator is included as part of the equipment. Voltage regulation of individual projectors makes possible equalization of illumination of the two projectors in any portion of the model being worked, thus improving the stereoscopic impression of the terrain. It is desirable to use the maximum illumination available, but portions of a model may require a decrease of the illumination of one projector to obtain equal lighting. Two types of voltage regulators are in service: the plug type and the dial type.

b. The dial-type regulator (fig. 15) has a box 5½ by 9 by 8 inches, which contains the transformer, and a box 8¼ by 10⅝ by 4¼ inches, which contains the regulator unit. Three cable connections are provided: one (1) on the primary side of the transformer for connection to the source of power; a second (2) for connecting the transformer and regulator; and a third (3) for connecting the regulator to the frame by means of the 13-conductor plug. The transformer has a primary voltage of 110-220 volts. A switch (4), located on the transformer unit, disconnects the transformer from the line. The regulator unit is provided with four circuits, A, B, C, and D, each of which can be used to supply current to each of the ten numbered outlets of the frame by setting the selector switch (5) for the cricuit being used to the number corresponding to the outlet which it is desired to light. Each circuit is controlled by a toggle switch (12). A rheostat (6) is provided on each circuit to control the intensity of illumination. By means of the voltmeter selector switch (7), the voltage on any of the four circuits may be read on the voltmeter (8). The maximum voltage which can be supplied at the outlets on the frame is approximately 21.5 volts with four lamps on. The rheostat

will reduce this voltage to 8 volts. When the rheostat is set at the index mark, the normal voltage for the lamps, 20 volts, is being supplied. At 21.5 volts the intensity of illumination is increased but the life of the lamp is decreased. An additional circuit which serves those outlets on the frame marked O (or T and L) supplies 21.5 volts at all times. Each of the five circuits is fused with a 10-ampere fuse located on the fuse block at (9). The line is fused by a 6-ampere fuse at (13). A shielded lamp (10), controlled by a switch (11), serves to illuminate the regulator unit.

c. In the plug-type regulator (fig. 16), both the transformer and the regulating unit are in one box, 8 by 8 by 12 inches. (One model is slightly larger.) Four circuits lettered A, B, C, and D are provided. The secondary cable of the voltage regulator is connected to the frame by means of a 13-conductor plug (1). Any one of the four circuits can be connected to any one of the ten numbered outlets of the frame by placing the brass plug (2) in the hole corresponding to the number of the outlet. The intensity of illumination of each circuit is controlled by a corresponding rheostat (3). By means of the selector switch (4), the voltage on any circuit may be read on the voltmeter (5). The voltage (and thus the intensity) can be varied from 8 to 20 volts. DO NOT PLACE TWO PLUGS IN THE SAME CIRCUIT AS THIS WILL RESULT IN OVERLOADING THE CIRCUIT AND BLOWING OUT A FUSE. An additional circuit which serves those outlets on the frame marked O (or T and L) has no rheostat and supplies 20 volts at all times. Each of the five circuits is fused with a 6-ampere fuse. If necessary to replace a fuse, the left side wall of the regulator must be removed. (One model has a small door on the side wall which gives access to the fuses.) Since there is no switch on the primary side, provision should be made for one when installing the regulator, or the plug on the primary cable should be disconnected from the power source socket when the regulator is not in use. The transformer has a primary voltage of 110 volts.

d. It is desirable to have the plug-type regulator set on a small table having casters. This arrangement allows the operator to move the regulator to a position that is convenient to him. Since the dial-type regulator is very light and easily moved, it is normally set on the multiplex table.

25. WIDE-ANGLE PROJECTOR.—a. The projector (fig. 17) is that part of the multiplex equipment which projects a reduced copy of the aerial negative in such a manner that the portion of the earth's surface which was photographed by the camera can be reconstituted in miniature as a spatial model. The projector consists of three main parts: body condenser, and lamphead. The camel's-hair brush for dusting the glass surfaces, the filter, and the projector bulb are included in the equipment. Figure 18 shows the projector completely assembled on the bar.

b. The projector body consists of a small-scale reproduction of the taking camera approximately 4½ inches in diameter and 2½ inches high, mounted so that it may be rotated about and translated along three perpendicular axes. In figures 17 and 18, the bracket (1) fits over the bar of the multiplex frame. Movement along the bar ("X" motion) is obtained by means of a knob

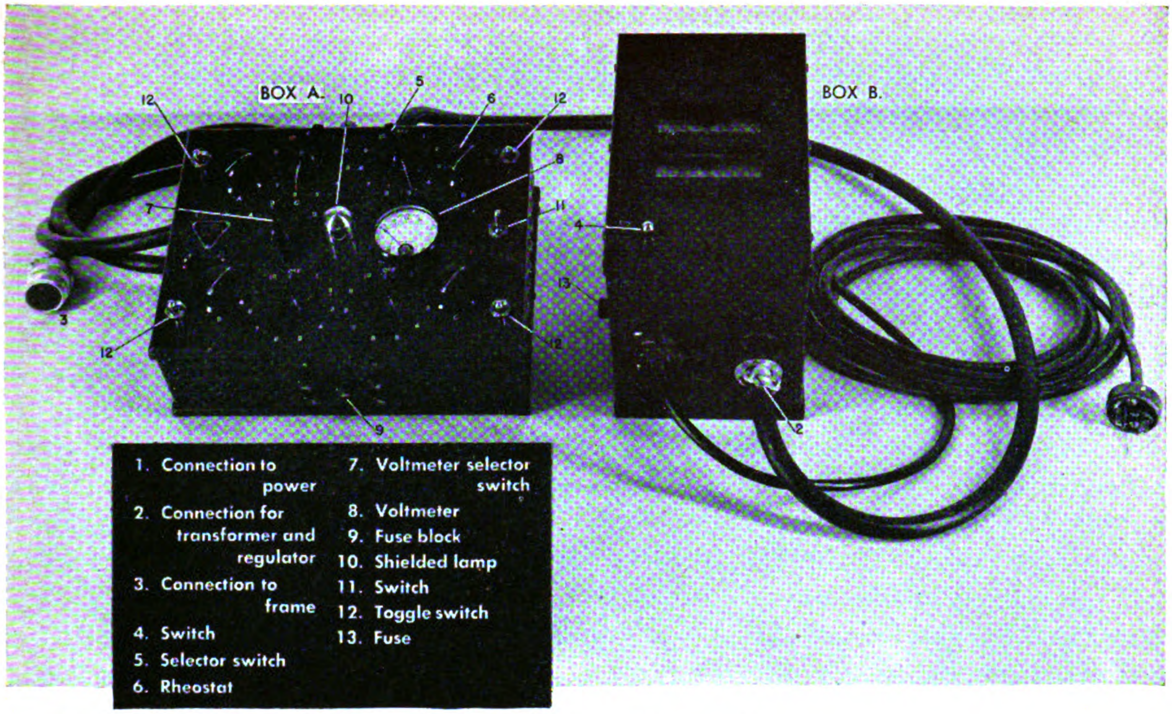

Figure 15.—Dial-type voltage regulator.

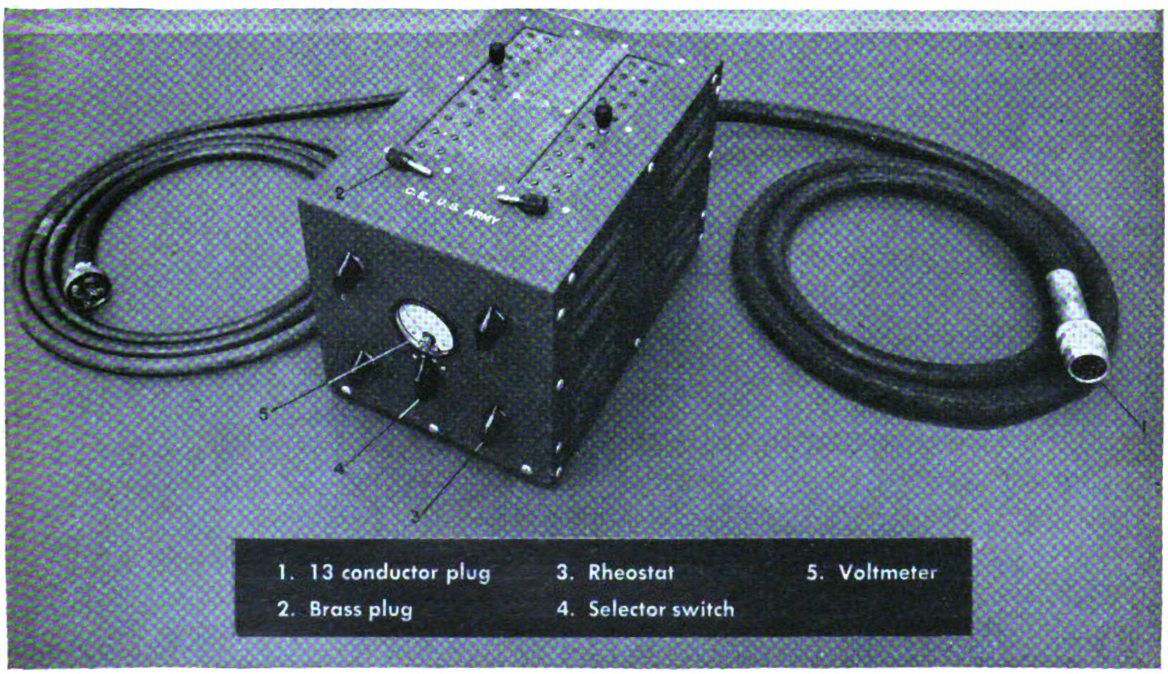

Figure 16.—Plug-type voltage regulator.

(2) which causes the pinion on the end of its shaft to engage with the rack on the bar. Movement in the vertical direction ("Z" motion) is accomplished by knob (6) which raises or lowers the projector with respect to the bracket and bar by means of the screw and vertical slide (3). The knob (7) engages a pinion with the rack on the horizontal slide (5) and moves the camera assembly horizontally, perpendicular to the bar. This is the "Y" motion. Attached to the horizontal slide is the ring support (8) which holds the camera assembly mounting (9) by two pivots (10). Rotation of the projector cone about the "X" axis (parallel to the bar) or tilt is accomplished by means of screw (12). Rotation about the "Y" axis (perpendicular to the bar in the horizontal plane) or tip is accomplished by means of screw (13). Rotation about the vertical axis or swing is effected by screw (14). All three screws act against levers which perform the desired motion on the cone assembly. On the opposite side of the lever from the screw, a plunger-type spring holds the lever in position. All three rotational motions can be moved approximately 10° in either direction. A screw (15) serves as a clamp for the swing motion. When this screw is loosened, the cone assembly can be rotated by hand through 360°. The projector lens is a wide-angle lens which has been designed to reduce distortion to a minimum and to produce the best definition at a projection distance of 360 mm. This is called the optimum projection plane. The magnification of the projector at 360-mm projection distance is 12.774 within 0.1 percent. The depth of focus of the lens is such that a projection distance ranging from 270 to 450 mm can be used. The projector is equipped with a glass stage plate (20), upon which the diapositive is placed and which serves as the focal plane of the cone assembly. The principal point of the projection camera is indicated by a small dot on the stage plate. Two thumb screws (27) are provided for centering the diapositive; that is, lining up the cross registered on the diapositive by the reduction printer with the dot on the stage plate. The thumb screws actuate the two plungers (26). Pressure of the spring (28) forces the diapositive against the two plungers to insure positive action. Three clips (22) are provided for holding the diapositive in contact with the stage plate. The center point in the boss (11) indicates the position of the transverse axis of the lens. The transverse axis of the lens is defined as the axis of rotation, for which there is no displacement in the projection plane of an image in the diapositive plane when the lens is rotated. The front (projection) node of the lens is located 2.1 mm above the transverse axis (nodes are reversed). Translational motions of the wide-angle projectors are equipped with rollers to permit smooth movements. The overall length of the projector body, including the horizontal slide and ring support, is 16 inches.

c. The condenser fits snugly over the projector body. The lower portion is equipped with condensing lenses which serve to produce even illumination over the entire area of the diapositive plate and which bring the light rays to a focus at the lens. The slot (23) above the condensing lenses is for the filter slide. Both red and blue-green filters are furnished. The upper portion of the condenser is threaded at

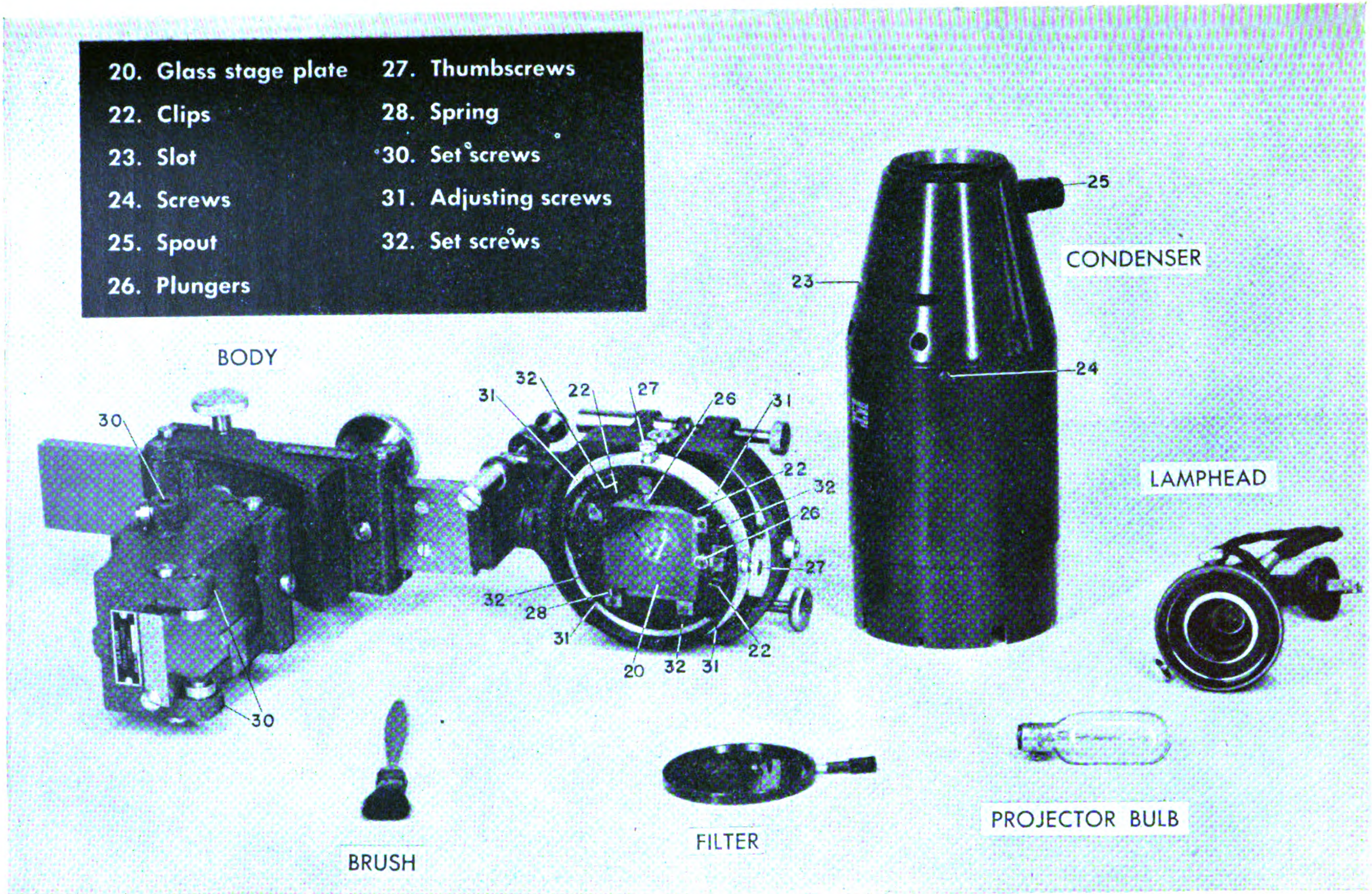

Figure 17.—Wide-angle projector dismounted.

the top for the lamphead. The spout (25) is provided for attaching the hose from the cooling header of the frame. By removing three screws (24), the upper part of the condenser can be removed in order to clean the upper lens surface. A coating has been applied to the inner surfaces of the condenser lenses in order to decrease reflection and increase the transmission efficiency.

d. The lamphead is equipped with a cord and a plug for connection to the frame. A 100-watt, 20-volt, contour-map projector lamp, with bayonet-candelabra base, fits into the socket of the lamphead. The lamphead screws on the condenser by means of the knurled ring (16). Means are provided for centering the filament of the bulb both vertically and horizontally; vertically by rotating the knurled collar (17), and horizontally by the two adjusting screws (18) which work against a spring. When assembled the condenser and the lamphead are 14 inches high.

e. The location of the principal point should be checked occasionally by rotating the projection camera (swing motion). If the principal point describes a circle in the projection, an adjustment is necessary. This adjustment is made by means of the four adjusting screws (31) held by means of set screws (32). The four adjusting screws move the circular plate upon which the stage plate is mounted. When the principal point no longer describes a circle, the setscrews (32) should be tightened.

f. Adjustment of the stiffness of movement of the "Y" and "Z" motions may be made by means of screws (29) which bear against a gib, which in turn presses against the slide. The vertical slide has this adjustment on both sides, while the horizontal slide has it on one side only. Care must be taken to make adjustment of the same mount on each end of the slide so that the perpendicularity of the translational motions may be maintained. Adjustment of the rollers of the "X" motion is required when there is a rocking of the bracket on the base bar of the frame. Adjustment may be made by means of the eccentric mounting of the rollers held by setscrews (30). While rollers of the "Y" and "Z" motions are also on eccentrics, adjustment of these will seldom be required. Rollers should be oiled occasionally to prevent rust.

g. Glass surfaces, such as objective lenses, condenser lenses, stage plates, diapositive, filters, and projection bulbs, should be dusted with the camel's-hair brush before each new multiplex set-up, as dust on any of the surfaces decreases illumination. Sliding surfaces should be wiped off occasionally with a cloth. The screws should be cleaned occasionally by wiping with a cloth, and lubricated with the lubricant furnished with the projectors.

h. The projector is one of the most delicate parts of the multiplex equipment and must be handled with care. Only those thoroughly familiar with the mechanical construction should attempt to make any repairs or adjustments to the instrument.

26. NORMAL PROJECTOR.—a. The normal projector differs from the wide-angle projector in size, weight, the optical system, the interior orientation system, and the mechanical movements. The normal projector is shown dis-

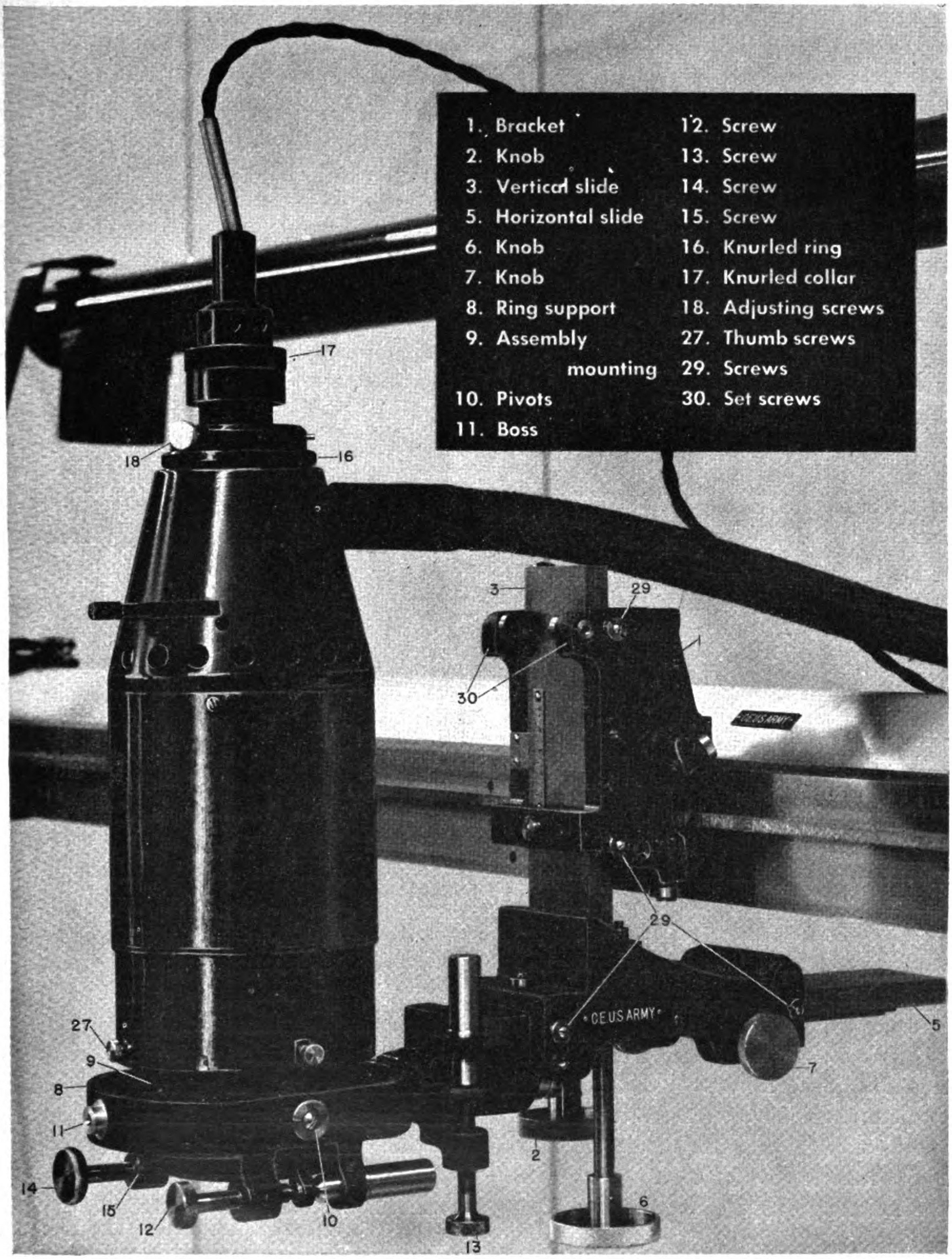

Figure 18.—Wide-angle projector assembled.

mounted in figure 19 and assembled in figure 20. The symbols used in describing the wide-angle projector in paragraph 25 are used in these figures, and the same description is applicable.

b. The assembled normal projector weighs only 11 pounds. The over-all length of the projector body, including horizontal slide and ring support, is 13 inches; the projection camera is approximately 3½ inches in diameter and 2½ inches high; and the condenser housing is 3½ inches in diameter and 9 inches high when assembled with the lamphead. All screws, by which movement of the projector is accomplished, and related parts are correspondingly smaller.

c. The projector lens is relatively free from distortion and produces best definition at projection distances of 360 mm with a depth of field sufficient to give reasonably sharp definition at distances varying from 270 to 450 mm. The nominal magnification of the projector at 360-mm projection distance is 7.819.

d. Movement of the diapositive for interior orientation is accomplished by means of the two eccentrics (21). These eccentrics, by means of an arm and roller, force the diapositive against two roller arms equipped with springs (19).

27. TRACING TABLES.—a. The tracing table is that part of the multiplex equipment which is used for viewing the stereoscopic model, measuring elevation in that model, and compiling the detail on the map sheet. The tracing table and its accessories are shown in figure 21. It is a stand 8 inches high, with a horseshoe-shaped base, 7½ inches wide and 6 inches deep, resting on three quartz footpads.

b. The operator views the projected image on a 4¼-inch white enameled circular screen or platen. Two types of screens are provided having different floating marks for measuring elevations: a luminous point and a "V." The luminous-point screen has a pinhole approximately .004 inch in diameter. (Some screens have a tilting feature which permits the screen to rotate about an axis through the floating mark to a maximum of 30° from the horizontal.) The base of the screen fits into its mount and is drawn tight by the threaded knurled collar (1). A lens in this mount, together with a lens in the base of the screen, tends to concentrate the light from a bulb in the support tube (2) into the pinhole. The screen and support tube can be raised and lowered on the vertical column by means of the knurled nut (3) on the elevating screw (4). The elevation of the floating mark can be read on a scale on the left hand column (5) by means of the viewing device (6). The viewing device consists of two mirrors placed at such angles that the operator can read the scale by looking into the window at the top. The scale is graduated in millimeters from 0 to 100 from an arbitrary datum. (On some of the earlier tracing tables the graduations are from 0 to 80.) Since all elevations read are relative, the absolute elevation of the table surface is unimportant. A vernier (7) permits readings to 0.1 mm. The index setting of the vernier can be changed by loosening the clamp screw at the rear of the vernier (not shown in the figure) and moving the vernier to the desired index setting by means of the knurled screw (8). A light in the tube (9), illuminating the index, is operated by the switch (10). A clamp (11) is provided for

Figure 19.—Normal projector dismounted.

holding the elevating screw and hence the elevation of the floating mark, at any desired setting. This is used in tracing contours. An extension 75-mm in length is provided for terrain in which the relief is so great that the 100-mm range of the tracing table is not enough. The tracing tables, which are graduated only to 80 mm, have two of these extensions, 50 mm and 100 mm in length. The extension is held on the screen seat by the threaded knurled collar (1), and the screen is fastened to the top of the extension by means of a collar (12) on the extension.

c. The drawing attachment consists of a pencil holder which slides over the vertical post (13). Lead is held in the pencil holder by means of the clamp (14). The screw (15) permits the adjustment of the lead. When the operator is not drawing, the pencil holder is in raised position and the lead is not in contact with the paper. When the operator wishes to draw, he presses the thumb hook at the rear of the cam slide (16) away from him and causes the pencil holder to be lowered so that the lead is in contact with the paper. To raise the pencil, the operator presses the plunger button on the back side of the cam slide toward him. Two bulbs in the base, operated by the switch (10) (which also operates the vernier light), illuminate the paper so that the operator can inspect his work.

d. The tracing table is wired to take the secondary voltage of the control unit and should be plugged into one of the sockets numbered O (or T and L) of the frame. All four bulbs in the table are 6–8 volt, 0.25-ampere, minimum screw base, frosted multiplex tracing-table lamps (fig. 21). The two bulbs in the base and the vernier light are connected in series and controlled by the toggle switch (10). The bulb under the screen seat is in series with a resistance and a rheostat (20), which regulates the intensity of light for the floating mark. This bulb can be reached by screwing off the cap (21). The knurled screw (22) serves as a clamp to hold the bulb in place. When loosened, this screw slides the bulb forward so that it can be removed. The vernier light can be reached by unscrewing the cap at the end of its tube and removing the set-screw on the top of the tube.

e. In order to convert the movement of the floating mark over the stereoscopic model into an accurate orthographic projection, the pencil must be exactly centered beneath the floating mark. The following test should be performed daily. With the floating mark clamped at any height, plot the location of a point projected from a single projector. Rotate the entire tracing table through 180° and again plot this point. The displacement between the two plotted points is twice the centering error. This error is removed by means of the adjusting screws (18) and (19). The two screws (19) also serve as a clamp and therefore must be loosened before corrections are made and tightened on completion of the centering. Exact centering of the pencil is obtained by repeating this procedure.

f. When a tracing table has been shipped or stored, and at various other times when a doubt exists, the verticality of the columns should be checked as follows. The test in **e** above is repeated with the floating mark in its highest and lowest positions. If each

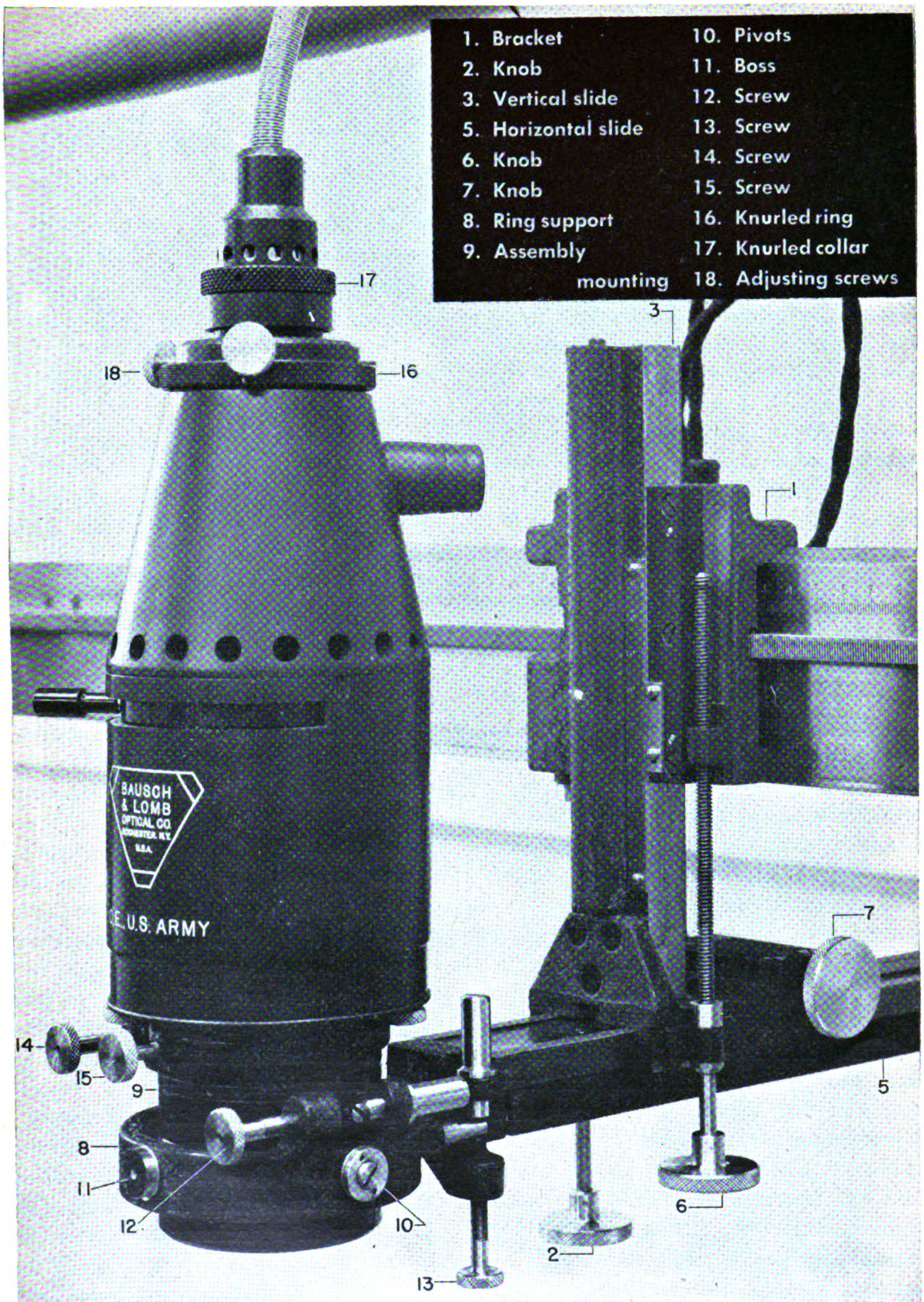

Figure 20.—Normal projector assembled.

pair of plotted points is coincident, the table is in adjustment. If each pair shows a displacement of the same magnitude and direction, the columns are vertical, but the pencil must be centered as described in e above. If the displacement of each pair of points is of different magnitude or direction, the columns are not vertical and the following adjustment is necessary: loosen the setscrews (23) and remove the plugs (24) above the footpads. The slotted top of the footpads can then be reached with a screw driver, and adjustment of height made. The adjustment must be by trial and error with the pattern of the plotted points as a guide. When verticality is obtained, replace the plugs and tighten the setscrews.

g. The operator should clean the columns daily by wiping with a cloth. Occasionally enough grit collects between the columns and the screen support sleeves to make vertical movement difficult and to mar the columns. This grit is removed as follows: with a spanner wrench, remove the caps (25) from the columns and the screw and washer (26) from the elevating screw. Pull the yoke off the columns and elevating screw and raise the screen support free from the columns. It may be necessary to detach the wires in order to clean the inside of the sleeves. The columns and sleeves should be freed from burs with crocus cloth. Remove grit and dirt with a cloth dampened with carbon tetrachloride or a similar solvent. Clean the elevating screw and its bearings and lubricate with light machine oil. When reassembling, tighten the screw (26) sufficiently to remove play in the elevating screw. The screen support should raise freely by means of the knurled nut. If play appears in the movement, tighten the nut underneath the screen support on the elevating screw with a spanner wrench. Easy operation with a minimum of play is desired.

28. WIDE ANGLE REDUCTION PRINTER.—a. The reduction printer contains the optical system by which a reduced copy on glass (diapositive) of the original negative is made. It consists of three main parts, as shown in figure 22: base, dome, and upper pressure plate. The completely assembled printer is shown in figure 23. The printer is wired for 110 volts and is equipped with a rheostat (14) for varying the illumination produced by the No. 211 photoenlarging bulb from maximum to 50 percent of a maximum intensity. The No. 212 photoenlarging bulb may also be used.

b. The base, which is 17 inches high and 17 inches in diameter, consists essentially of the negative plane, and a means of illuminating the negative. On the lower pressure plate (1) are etched collimating marks for orienting the negative. Under this plate are two ground glasses for diffusing the light and a No. 211 or No. 212 photoenlarging bulb, located at the focal point of a parabolic reflector. The bulb is held in place by two wing nuts which allow it to be shifted about for centering. A toggle switch is located at (4). A slide (5) permits the insertion of a dodging disk for dodging uneven negatives. Film brackets (6), which are located on both sides, can be raised and clamped by wing nuts in a horizontal position for operation (fig. 23). Four prongs in the upper pressure plate fit in holes provided in the top of the base. The film

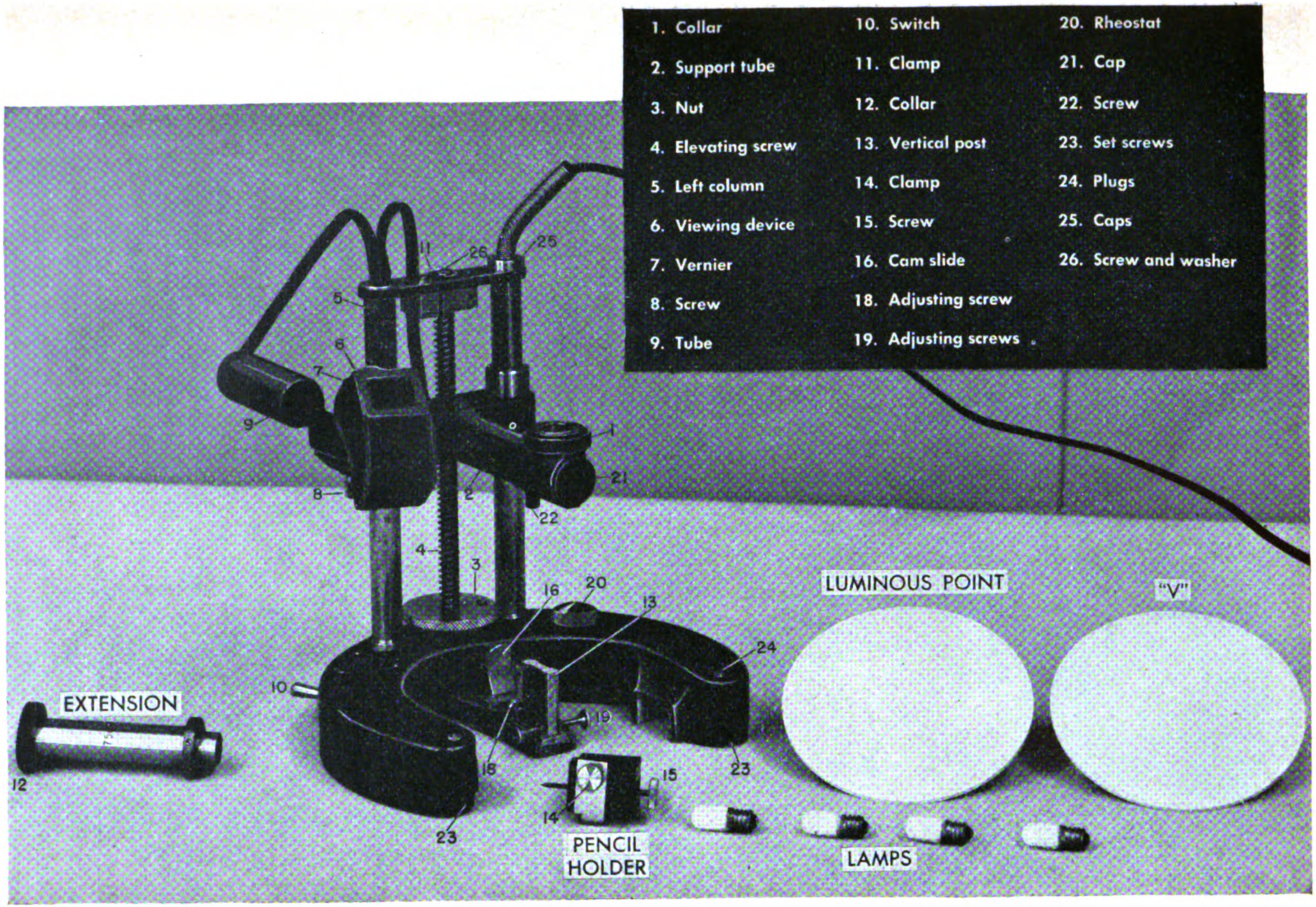

Figure 21.—Tracing table and accessories.

is passed between the upper and lower pressure plates with emulsion down. A foot pedal (7) raises the upper pressure plate, relieving the pressure so that the film can be more easily oriented on the collimating marks. An electrical cord connection is furnished for attachment to the power outlet.

c. The dome carries the diapositive plane, the printer lens, the compensating lens, alinement windows, and two knurled rings (8) by means of which the desired reduction is set. The height of the dome is 20 inches. The diapositive stage (9), upon which the unexposed diapositive is placed, has an opening $1\frac{11}{16}$-inches square, upon which the 54-mm by 54-mm diapositive is placed during exposure. Stops are provided for placing the diapositive on the stage so as to be properly positioned. Clips (10) are provided for holding the diapositive in position. A dust cap (11) is furnished for covering the opening. The printer lens has opposite distortion characteristics from those of the Metrogon camera lens, so that when a negative is reduced a diapositive relatively free from distortion is produced. A compensating lens for varying the intensity of the light in the corners is operated by the knurled screw (12). When the compensating lens is in its lowest position, that is, when the screw is turned to a stop in a counterclockwise direction, the greatest intensity of light in the corners is obtained. When the compensating lens is in its highest position, the minimum intensity of light in the corners is obtained. There are four alinement windows fitted with red glass filters for viewing the alinement of the collimating marks of the negative with those on the glass plate; one is $2\frac{3}{8}$ inches in diameter, the other three are 1 inch in diameter. Adjustment of the reduction ratio is accomplished by movements of both knurled rings (15) and (16). The movement of the first ring spaces the lens at the correct distance from the negative plane, while that of the second places the diapositive stage in its correct position. Scales are provided (17) and (18), graduated in camera focal length which can be read to 0.1 mm. The reduction may be set for focal lengths varying from 151 mm to 155 mm. Both scales must be set at the same figure, which is the focal length of the negative being reduced. Two clamps (13) are provided for holding the dome fast to the base.

d. All glass surfaces must be kept clean and free from dust, a camel's-hair brush being provided for cleaning the lens surfaces. The pressure plates, which hold the film, should be cleaned thoroughly with a chamois skin or a soft, lintless cloth. The printer should be handled with care. Since it is extremely important that the negative plane and diapositive plane remain parallel when diapositives are made, no dirt should be allowed to lodge between the surfaces of contact of the dome and the base, and the clips (10) should be fastened when exposures are made. When the clamps (13) are fastened, there should be no play between the dome and the base. Since the optical system of the printer must be kept accurately in adjustment, no individual should attempt to alter it, If adjustment is necessary, the printer should be returned to the factory.

e. The stand shown in figure 23, while not part of the equipment, is used in order to raise the printer to a height more convenient for operation. The stand, 18 inches high and 18 inches

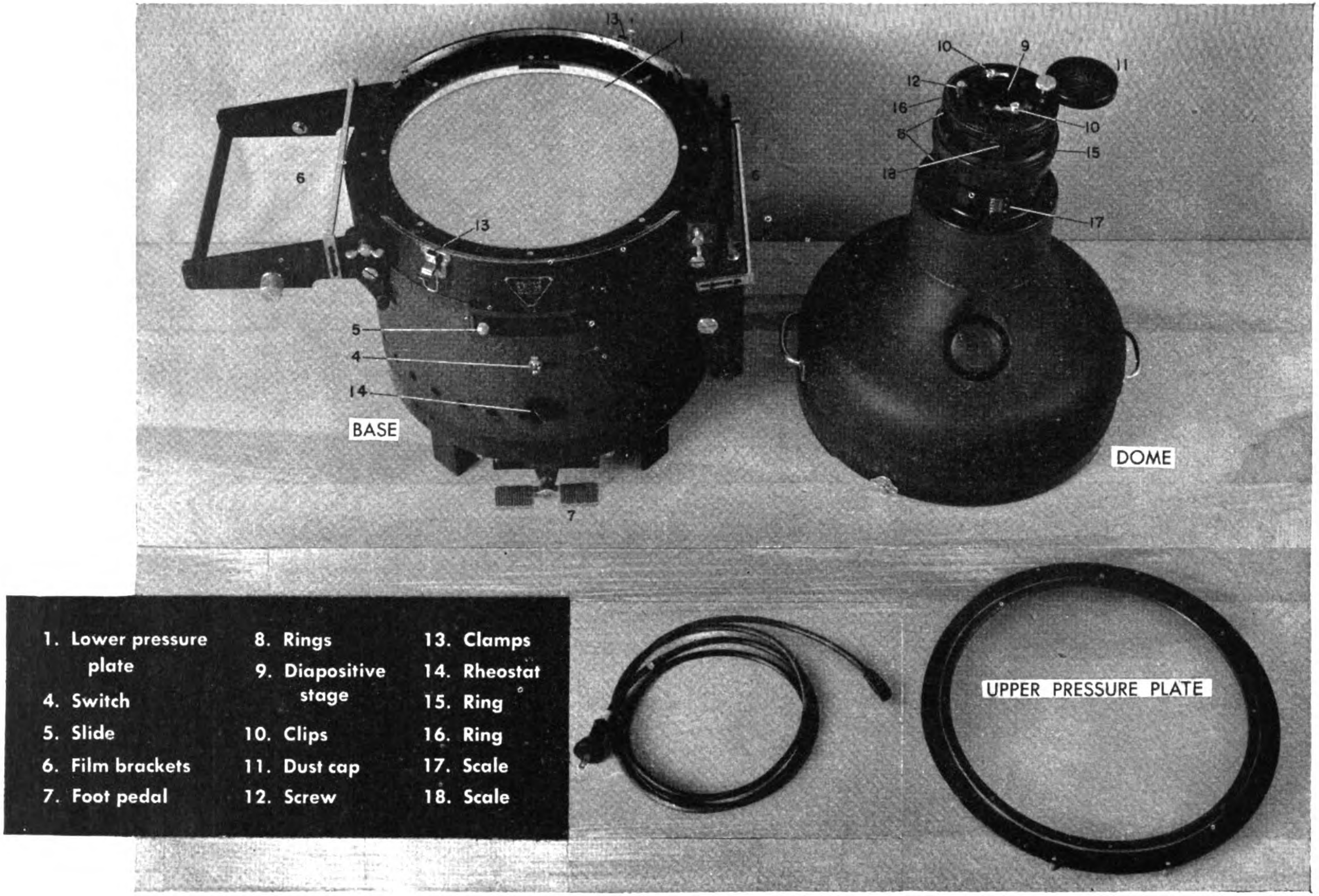

Figure 22.—Wide-angle reduction printer dismounted.

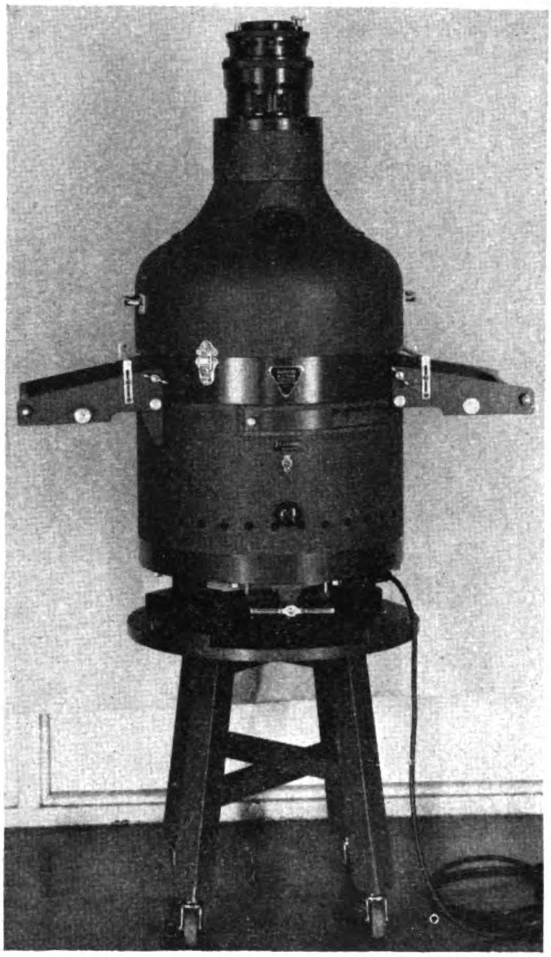

Figure 23.—Wide-angle reduction printer assembled.

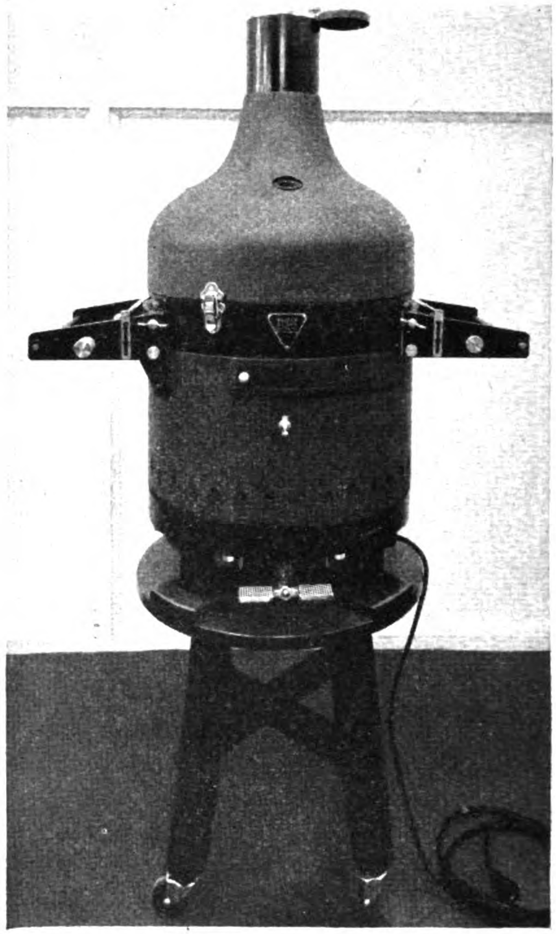

Figure 24.—Normal reduction printer assembled.

in diameter, is made of wood and provided with casters and blocks for holding the printer feet.

29. NORMAL REDUCTION PRINTER.—

a. There are two types of the normal reduction printer, both of which are similar to the wide-angle printer except for the size, optics, and the variable reduction ratio. An assembled printer is shown in figure 24.

b. The reduction ratio of the type I reduction printer, used with 6-inch T–3A negatives, is fixed at 0.308±0.2 percent, while the reduction ratio of the type II printer, used with the 8¼-inch K–3B negatives, is fixed at 0.219±0.3 percent. The height of the dome on the type I printer is 16½ inches, and it has a diapositive stage opening of 1$^{11}/_{16}$ inches by 1$^{13}/_{16}$ inches. The height of the dome in the type II printer is 20 inches, and it has a diapositive stage opening of 1$^{9}/_{16}$ inches by 2 inches. The objective lenses in both printers are relatively free from distortion. The base of the normal printer is identical with that of the wide-angle printer.

c. These printers are wired for 110 volts (the first model was wired for 20 volts). Some of the printers are equipped

with the 60-watt outside frosted bulb, but later models use the No. 211 or No. 212 photoenlarger bulb and are equipped with a rheostat for reducing the intensity of illumination from maximum to 50 percent of maximum.

30. MISCELLANEOUS EQUIPMENT.—
a. Projector levels.—The wide-angle projector level shown in figure 25 is designed for use with the wide-angle projectors for the purpose of measuring the angles of tip and tilt at which the projector has been set and for adjusting it to a predetermined inclination. It consists of a base (1), which may be attached to the projector in place of the condenser, and above it a casting (2) carrying a bubble level (3) and an observing microscope (4). The base has a swinging arm (5) with a slot to engage the boss on the projector for the purpose of securing proper orientation of the projector level with respect to the projector. The swinging arm is held away from the projector when not in use by means of a catch (6). When released from the catch the arm is held against the projector bracket by the action of a coil spring (7). The casting may be rotated about the base so that the cross line in the observing microscope may be alined with the collimation marks on the diapositive and locked in the desired position by means of the clamp screw (8). The swing of the diapositive with respect to the projector may then be read on the graduated circle on the rotating portion of the instrument. Direct readings to 15 minutes of arc may be made with the aid of the vernier attached to the base. The level is mounted on an arm attached at one end of a horizontal bearing; about this bearing the arm can be caused to rotate in a plane perpendicular to the base of the instrument by the action of an adjusting screw working against a spring plunger. At the other end is a scale and vernier graduated to read angles up to 10 above and below the horizontal, with a least reading of 5 minutes of arc. The instrument has the same weight as the condenser. The normal projector level is shown in figure 26. Its construction is similar to that of the wide-angle projector level except that no provision is made for

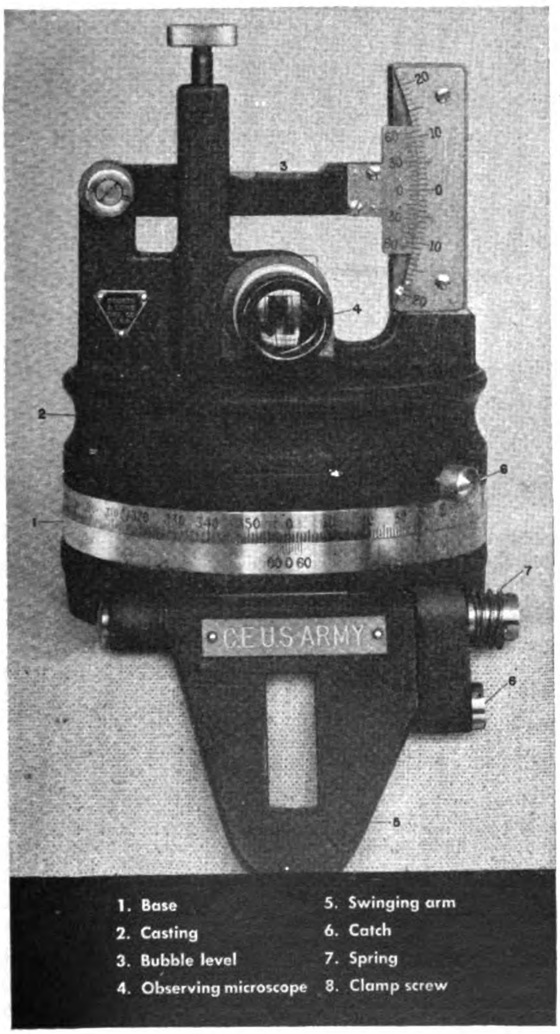

Figure 25.—Wide-angle projector level.

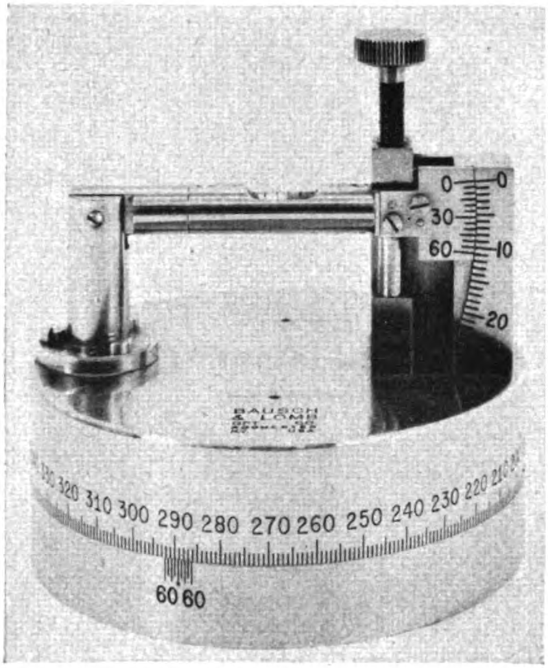

Figure 26.—Normal projector level.

orienting it with respect to the projector or the diapositive. The angle of inclination may be read below the horizontal up to 10°.

b. Height gage.—The height gage (fig. 27) is used for measuring the height of the projector above any datum plane. The height gage is 18½ inches high when extended and 13½ inches high in its carrying position. The three clamps (1) are used for fastening the base to the screen of the tracing table. When the indicator (2) rests on top of the boss on the projector the correct height from the base to the bottom of the indicator is 6 mm more than the value read, but since the radius of the boss is 6 mm, the correct height of the center of the projector boss is read directly. The tube, which is graduated in millimeters from 260 to 460 and which can be read by means of a vernier to tenths of a millimeter, is keyed to the slide which carries the indicator. A ring (3) clamps the slide to the tube. A ring (4) is the micrometer movement for the vernier. A screw (5) is the clamp on the micrometer movement.

c. Lead sharpener.—By means of the lead sharpener (fig. 28) leads are sharpened to a point concentric with their stock for use in the multiplex tracing table. Leads are sharpened by the simultaneous rotation of the chuck (1) which holds the lead to be sharpened in its adjustable jaws, and of an emery disk (2) inclosed under the guard. The chuck is held in the chuck holder so that it makes an angle of 12½° with the plane of the emery disk. Rotation is accomplished by means of the handwheel (3) and the geared connections. By means of a ratchet, cam, and lever arrangement (4) the emery disk is moved in a horizontal direction gradually toward the lead, so that the lead is sharpened by the abrasive action of the emery disk. At the end of each sharpening cycle, the emery disk returns automatically to its starting position. An adjusting screw (5) is provided for setting the initial position of the emery disk. The instrument may be fastened to the side of a table. A drawer is provided under the emery wheel to collect the lead dust.

31. PACKING.—**a.** The multiplex equipment should always be transported in the special cases provided for it. If the instruments are to be shipped, these cases should be inclosed in another box and a cushion of elastic material should be placed on all sides between the case and the shipping box in order to prevent direct transmission of shocks to the instrument from rough handling in transit. Shipping boxes should be

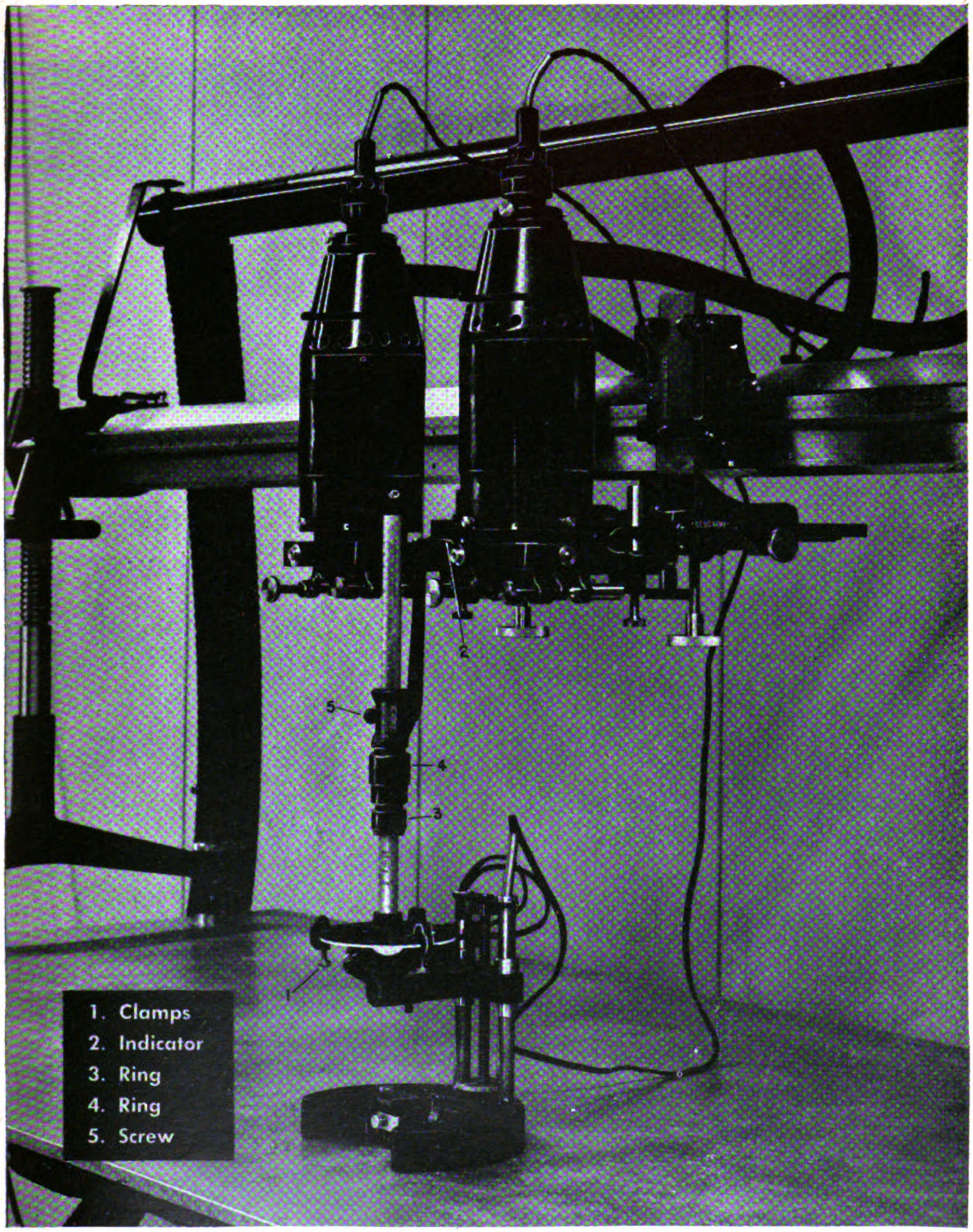

Figure 27.—Measuring projection distance with height gage.

marked: "Delicate instruments—this side up—handle with care." They should be shipped by express rather than freight.

b. The following table on the page opposite shows the grouping of the equipment in cases, size of the cases, and the approximate shipping weight of each, crated.

32. CARE OF EQUIPMENT.—a. Tools are provided in each case to set up the instruments for operation and to make minor adjustments. Adjustments and repair of the instruments should not be attempted by anyone who is not thoroughly familiar with their construction and operation.

b. Too much emphasis cannot be laid upon the importance of care in handling instruments. It should be the duty of each operator to whom the equipment is assigned to keep his instruments cleaned and properly lubricated. The threads of the tangent screws, the projector slides, and the vertical columns of the tracing table are particularly likely to collect dust and grit and should be frequently cleaned and lubricated.

c. The glass surfaces should never be rubbed with a rough cloth or touched with the fingers, as the glass may be permanently scratched. Special cleansing tissue or a soft lintless cloth should be used to clean them after they have been dusted with a clean camel's-hair brush. Special care must be taken in this respect when placing diapositives on the stage glass. Dust thoroughly both the stage glass and the diapositive immediately before placing the diapositive in position.

d. Special precautions should be taken with each item of equipment as given in preceding paragraphs.

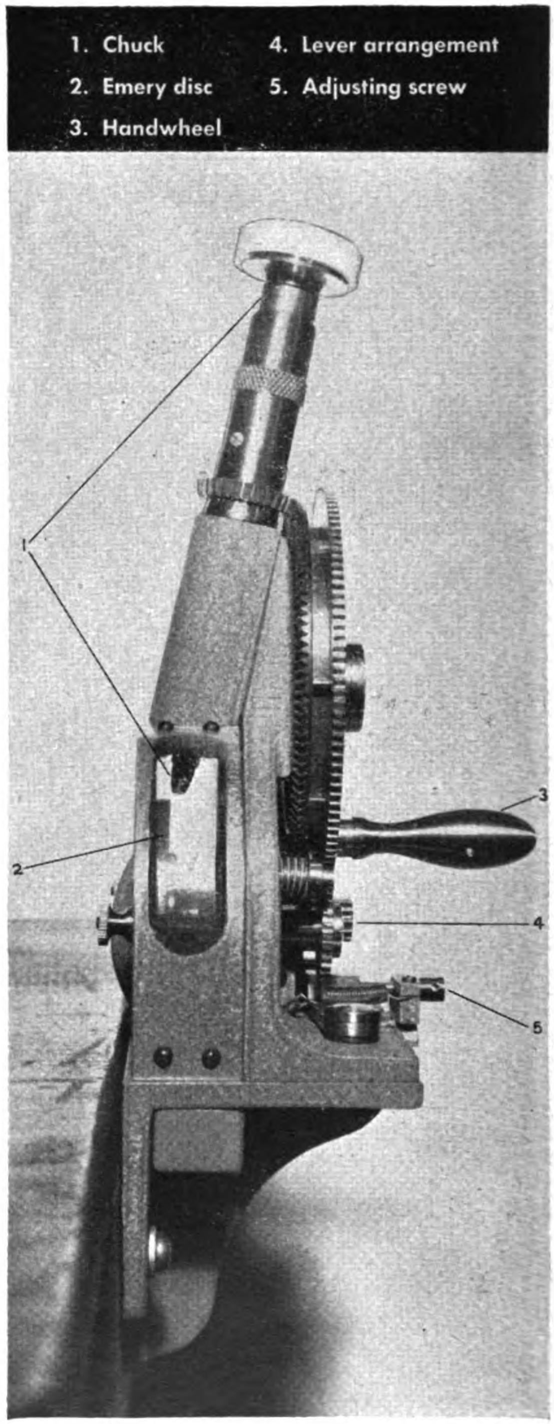

Figure 28.—Lead sharpener.

Case	Item	Case dimensions	Approximate shipping weight crated (pounds)
1	Table		530
2	Frame, normal	24¼ x 84½ x 10¾	380 est.
3	Frame, wide-angle Height gage Projector level Voltage regulator Transformer	25½ x 87¼ x 12¾	450 est.
4	Cooling unit (suction type)	21 x 24 x 27	275 est.
5	Cooling unit (blowing type)	21¾ x 21¾ x 27	300 est.
6	Voltage regulator (plug type)	11¼ x 12½ x 19	75 est.
7	Projectors, wide-angle, 3 ea Tracing table	14 x 18¾ x 34	200
8	Projectors, normal, 3 ea Tracing table Control stands	14¼ x 14½ x 27¼	160
9	Reduction printer, wide-angle	21½ x 22½ x 41½	365
10	Reduction printer, type I	21½ x 22½ x 37	365 est.
11	Reduction printer, type II	19¾ x 22¼ x 40¼	365 est.
12	Center support, wide-angle	8½ x 20 x 73¾	350 est.
13	Center support, normal	8¼ x 20 x 73¾	340 est.

SECTION IV

OPERATION

33. GENERAL.—This section contains detailed instructions for the use of multiplex equipment, except the reduction printer which is discussed in section V. The procedure is practically the same whether the normal or the wide-angle equipment is being used.

34. PRELIMINARY.—In starting the multiplex operations, the table is leveled and the bar centered and leveled thereon. For the wide-angle projector the bar is located near the far edge of the standard multiplex table, while for the normal projectors the proper position is near the center of the table. The table top is the reference plane; hence, it could be in any position, but a level one is desired for convenience in making first adjustments of the remaining apparatus. Projectors are hung on the frame by means of the projector bracket. A turn of the "X" motion insures proper meshing of the pinion on the rack. The "Z" slide is set at approximately the center of its range of travel and the height of the projectors is then adjusted by raising or lowering the bar until the lens is approximately 360 mm above the surface of the tracing table platen when the elevation of the tracing table is set in the middle of its range. The projector may be leveled with the projector level or any level placed on the stage plate. Care should be exercised not to scratch or in any way mar the surface of the stage plate. Ths most probable position of all projectort is that obtained by assuming the flight altitude constant and the camera vertical; hence, if all equipment starts level, a minimum amount of change should be necessary in the steps that follow.

35. LIGHTING.—**a.** Lampheads, lamps, and condensers are assembled. With the camel's-hair brush, remove the dust from all glass surfaces which can be reached. The condenser is carefully slipped over the top of the projector body, the cooling attachment connection is made, and the light cable plugged into a proper socket on the frame.

b. Each projection should be evenly illuminated and free from spectral color. Centering the lamp filament with respect to the condenser and the lens

opening accomplishes this. Two adjusting screws work against a counterspring for shifts normal to the projector axis, and rotation of the knurled collar provides movement along the axis. Correct illumination is obtained when the field is clear or when only a slight, evenly distributed color remains in the corners between red-yellow and blue-yellow.

36. INTERIOR ORIENTATION.—**a.** This term refers to obtaining the same angular relationships in the projection as existed when the picture was taken.

b. Before inserting the diapositive in the projector, the edges should be scraped with a knife to remove all roughness of the emulsion on the edges of the plate. The stage plate and the diapositive should be carefully dusted with the camel's-hair brush. The retaining spring is held out of the way, and the diapositive is placed, emulsion side down, on the stage plate. Releasing the retaining spring shoves the diapositive against the opposing plungers and holds it firmly in place. The diapositive should be tapped lightly with a pencil or other solid object at the four corners of the plate to assure perfect contact. The three hold-fast clamps are swung into place, holding the diapositive down. The condenser is then replaced and the light turned on.

c. Near the center of the projection will be noted two marks, a cross and a dot. The dot is the principal point of the projector and the cross is the principal point of the photograph. The two marks must be brought into coincidence by centering the diapositive on the stage (pars. 25*b* and 26*d*). When perfect coincidence is obtained, interior orientation is correct and the projection is ready for combination with another to form the stereoscopic model, that is, relative orientation.

37. RELATIVE ORIENTATION—GENERAL.—**a.** Interior orientation having been completed on adjacent projectors containing an overlapping pair of diapositives, filters of complementary colors are inserted in the slots provided in the condensers. Spectacles fitted with the same filters are worn, the left eye looking through a filter similar to that used in the left projector and the right eye through a filter similar to that used in the right projector, in order to obtain the required image separation which results in stereoscopic vision or perception. When the spectacles are placed on the operator so that the left eye looks through a filter similar to that used in the right projector, and the right eye looks through a filter similar to the one in the left projector, a pseudoscopic model is seen, or one in which valleys appear to be ridges in the model, and hills appear to be depressions. Viewing a model in this manner sometimes helps the operator to trace out drainage or depressions that are difficult to see in the normal view. However, contours should not be traced while the model is viewed with the glasses reversed, nor should a model be horizontalized while so viewed.

b. To obtain a true stereoscopic model, it is necessary to make the corresponding rays from each of the two projectors intersect in space. Before orientation, the overlapping projections will appear on a horizontal plane, as illustrated in figure 29. The corresponding rays do not intersect in space; hence on all horizontal planes cutting

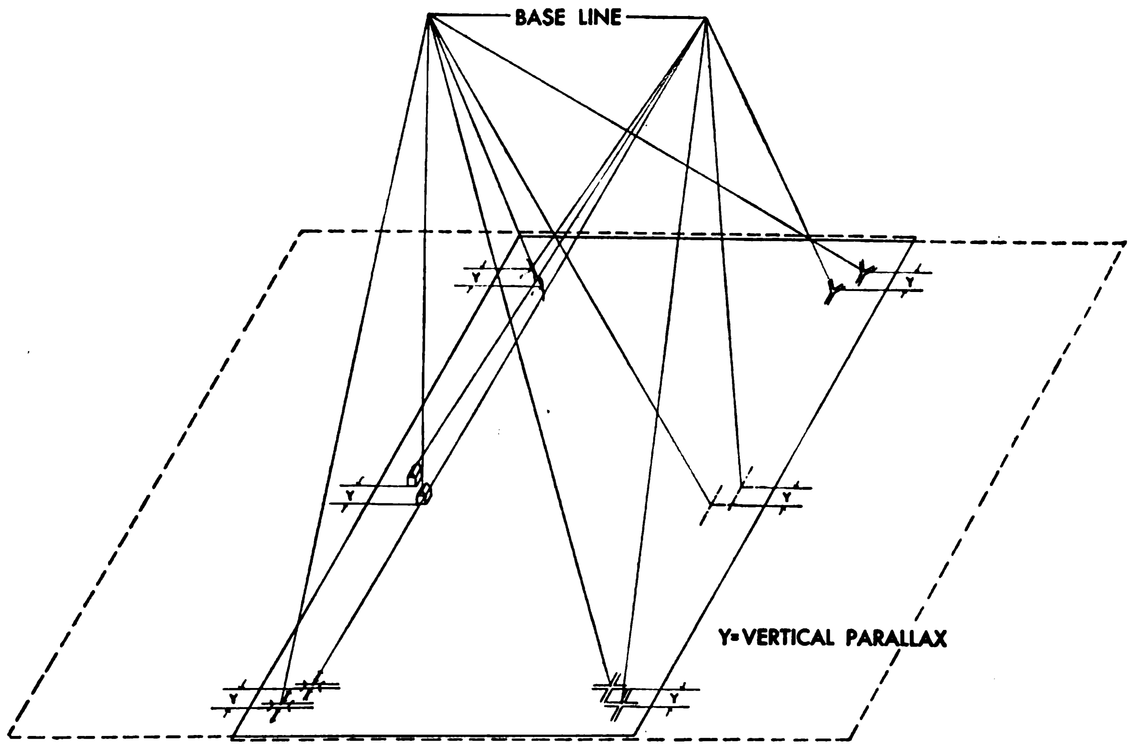

Figure 29.—Overlapping projections before orientation.

the two cones of rays they will appear as two-point images. The displacement between these two-point images may be resolved into two components, one of which is parallel to the vertical plane containing the line joining the two ray centers (lens nodes) and the other component perpendicular thereto. This perpendicular component is called the vertical or "Y" parallax. The component parallel to the vertical plane containing the base line may be reduced to zero by selecting the proper horizontal plane, that is, by raising or lowering the tracing table platen; but the perpendicular component or "Y" parallax can be reduced to zero only by adjusting the orientation of the projectors with respect to each other. This is done by a trial and error process, but a definite procedure is followed which is quite brief.

The two projections, after orientation, will appear as illustrated in figure 30 for the assumed case of equal flight altitudes. All corresponding rays intersect to form planes which also contain the line joining the two ray centers (lens nodes) or the "base line." On any horizontal plane, the corresponding rays appear as point images and the line joining them is parallel to the vertical plane containing the base line. The distance between the two images is an indication of the height of the actual point in space and is known as horizontal or "X" parallax. When this horizontal parallax is reduced to zero, in the properly oriented model, by selecting the proper horizontal plane (that is, by raising or lowering the tracing table platen), the actual position of the point in space is determined and the elevation

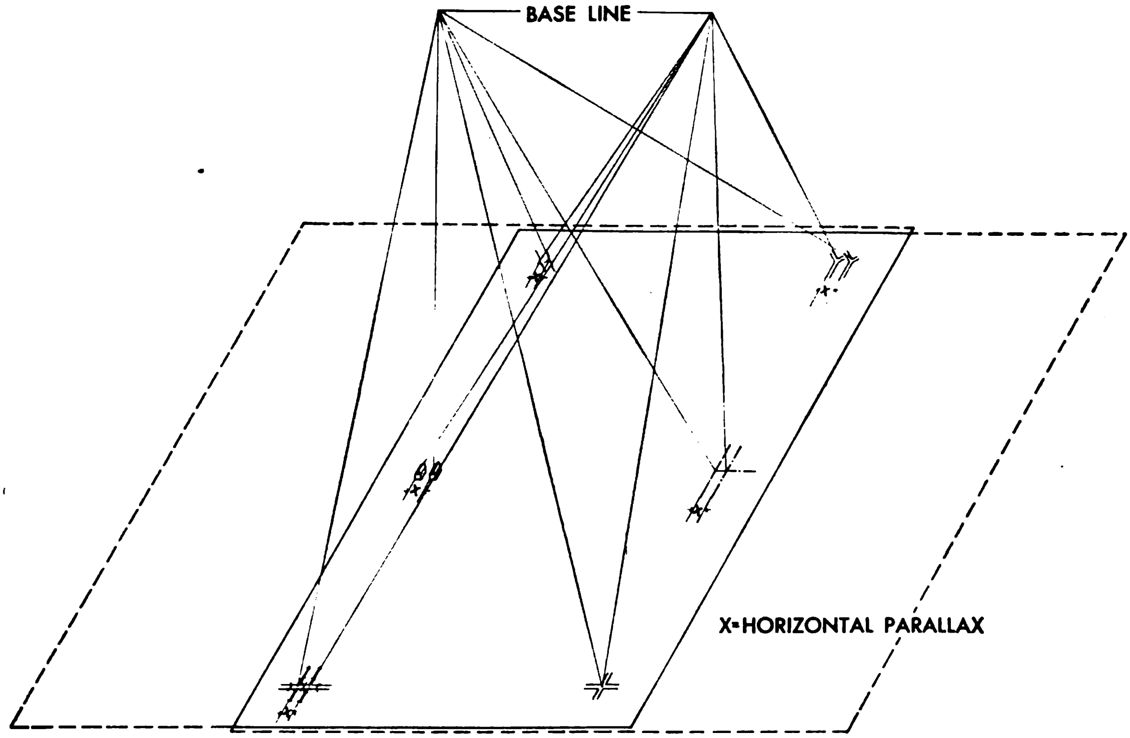

Figure 30.—Multiplex model properly oriented.

(to scale) can be read. Where the flight altitudes are not equal, the displacement on any horizontal plane between the two-point images in a correctly oriented model will not be truly parallel to the vertical plane containing the base line. However, in practice, the flight altitudes are generally so nearly equal that the assumed case of equal altitudes will apply. In multiplex operations, the vertical or "Y" parallax is commonly referred to simply as parallax and will be so referred to hereafter.

c. There are six elements of exterior orientation, that is, six movements that can be given to each projector to bring it into its proper position. The movements are—

(1) "X", movement along the X-axis or along the bar. The mean line of flight should be set parallel to this movement.

(2) "Y", movement perpendicular to the X-axis and along the Y-axis. It is parallel to the datum when the bar is properly leveled.

(3) "Z", movement in a vertical direction, used to adjust the flight altitude.

(4) "*Swing*", rotation of the projector around its vertical axis.

(5) "*Tip*", rotation of the projector around a horizontal axis parallel to the Y-axis, similar to nose up or nose down of the airplane.

(6) "*Tilt*", rotation of the projector around a horizontal axis perpendicular to the tip axis, similar to a wing up or down in the airplane.

d. It is well for the operator to have a comprehensive idea of the effect produced in the projection by a change in each of the elements of orientation. It must be kept in mind that each projection is a perspective "bundle of rays," and that planes cutting this bundle of rays at various angles form patterns

varying in shape and size, and similar to those found in conic sections. With this in mind it is not hard to analyse small amounts of parallax and make the proper movement to eliminate it. The beginner should turn on a single projector and then move each of the six elements of exterior orientation, carefully noting the effect of each movement on the projection formed on the table. For this purpose it is preferable to use a single grid diapositive. It will be noted that "X" and "Y" motions are simple translations with no change in the projection. "Z" motion causes a uniform change of scale with no movement at or near the center. "Swing" simply rotates the projection with

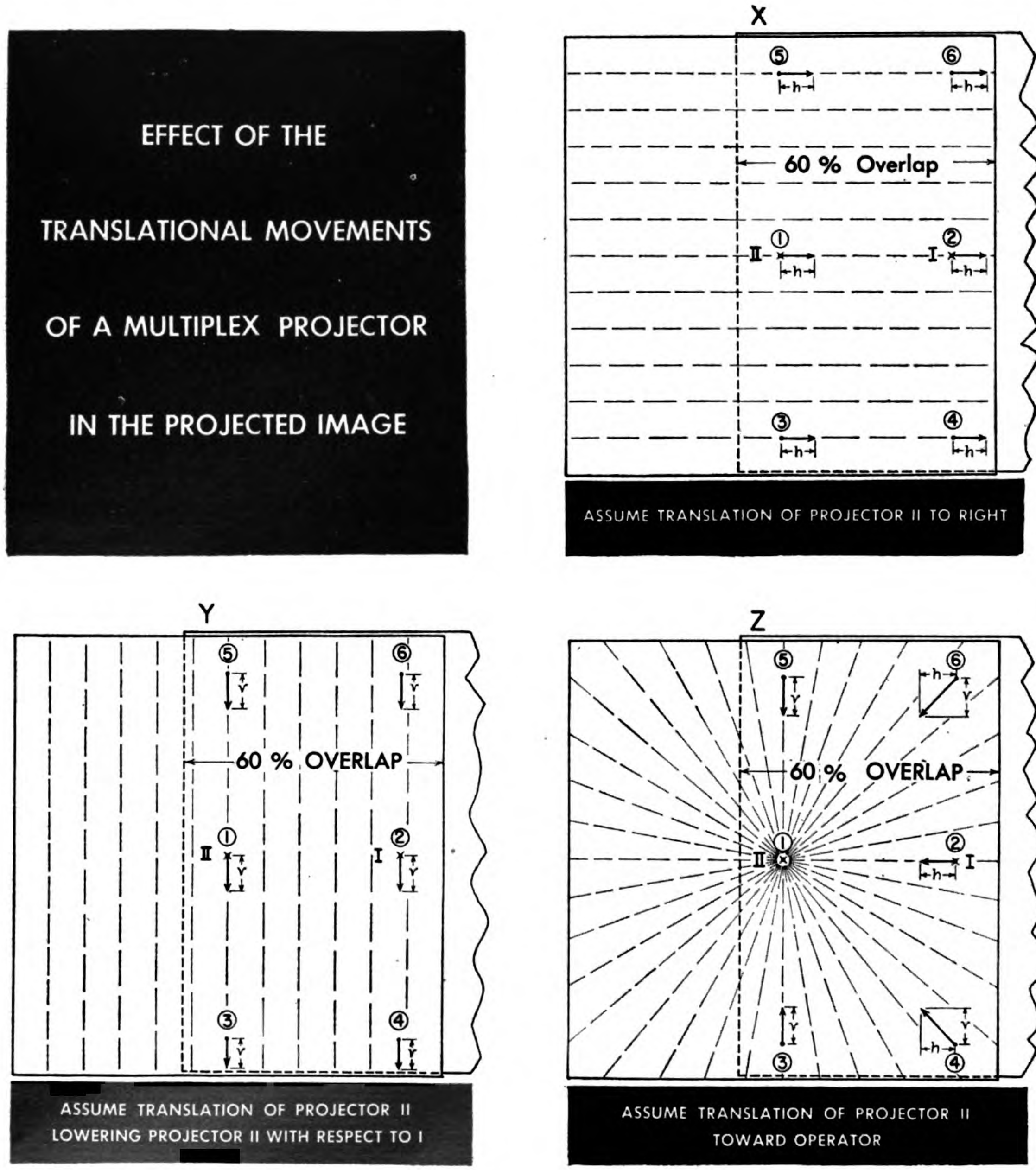

Figure 31.

little or no change in scale and shape. "Tip" and "Tilt" cause irregular changes of scale, but it will be noted that the scale becomes larger on one side of the axis of rotation and smaller on the other. Figures 31 and 32 show the effect in the projected image of moving each of the six elements of orientation. By means of these charts and by practicing the movements with a single projector, the student should become familiar with the effect of each movement. The resolution of the movement into its components of horizontal and vertical parallax at the six points normally used for the removal of parallax (par. 38*c*(1)) should be carefully noted.

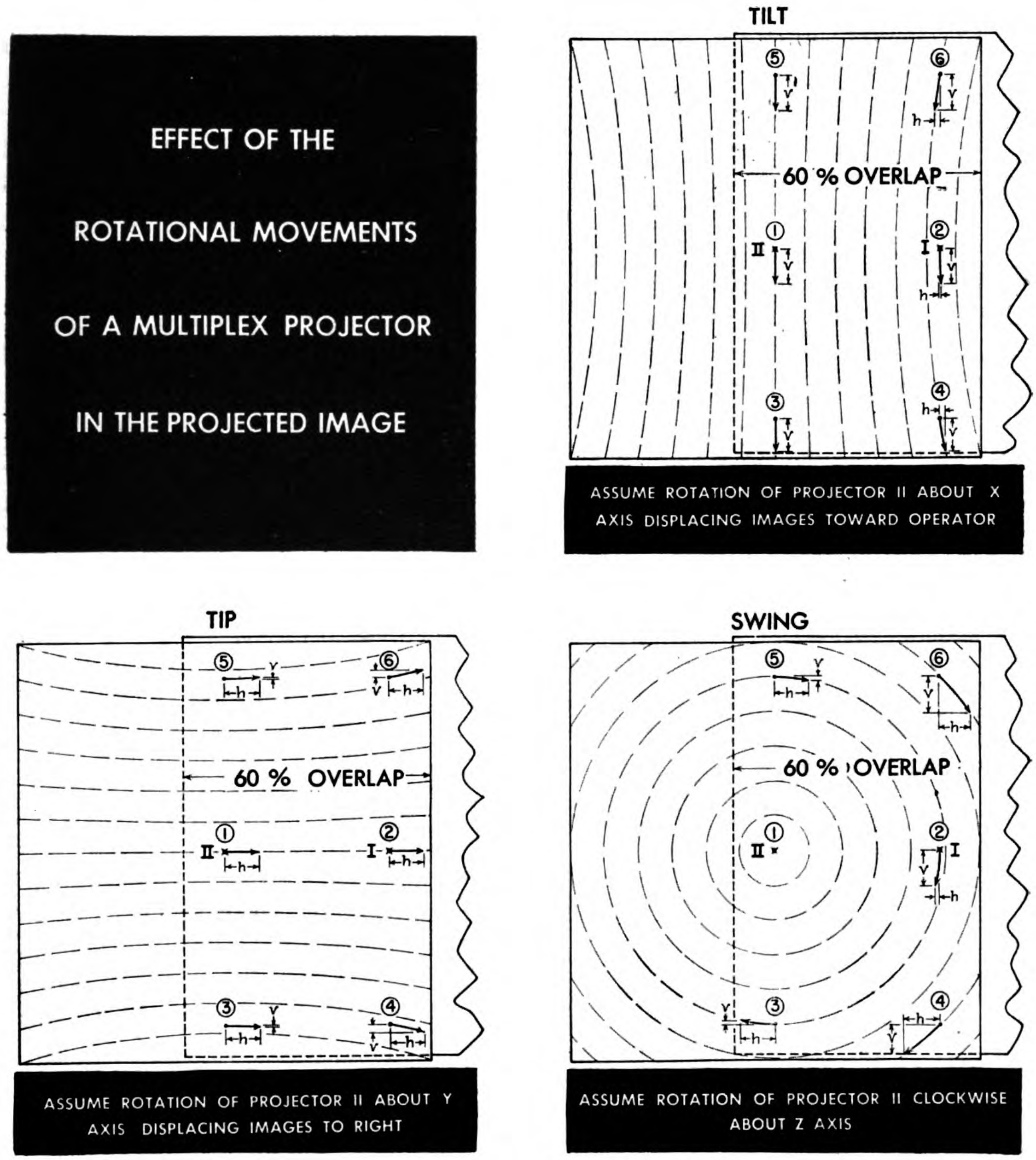

Figure 32.

38. RELATIVE ORIENTATION—DETAILED.—**a.** In order to simplify the procedure for removing parallax, certain well-defined images are chosen at six different positions in the model, indicated in figures 31 and 32 as points 1 to 6. If the parallax is removed from each of these positions, the model as a whole will be correct. For first attempts at removing parallax it is advisable to use grid diapositives and to orient the model without wearing the filter spectacles, so that the operator will become acquainted with the effects of the different movements and with the general procedure to be followed; terrain plates may be confusing to the beginner. After the relative orientation of the grid model has been performed several times, the beginner should attempt to orient the grid model while wearing the filter spectacles. This will be found to be a little more difficult, but must be mastered as accurate relative orientation of terrain models cannot be accomplished without wearing the filter spectacles.

b. After the beginner is able to orient grid models satisfactorily he is ready to attempt orientation of a terrain model. In order to remove parallax from the model, obviously the operator must be able to recognize parallax when present in the model. If the projectors are far from proper adjustment, the view presented to the eye, when the projections are viewed wearing the filter spectacles, is a mottled maze of images and is very confusing. By applying the proper motion to one of the projectors to remove the parallax at the position being viewed, a point will be reached where each eye will simultaneously see a view of the same object or area, and there will appear to be one image with relief. By concentrating on the stereoscopic view presented to the observer and at the same time becoming conscious of the floating mark (the dot or *V* on the tracing table platen) in the field of view, it will probably be noticed that this mark appears to be above or below the height of the model and will most probably appear double. By raising or lowering the tracing table platen, these two images of the floating mark can be made to appear to touch the surface of the model, and one image of the floating mark will appear to be directly above the other in the *Y* direction. Although the model is now fairly sharp and clear the parallax is not yet entirely removed. Continuing the movement of the projector to remove the parallax at the position viewed, these two images of the floating mark will appear to merge into one image, at which point the parallax is removed at this position in the model. Provided there is not too much parallax in the other positions of the model, the stereoscopic view will be sharp and pleasing to the eye.

c. Two methods are given: In the first, one projector is held stationary and all movements are made on the second projector; in the second method, the rotational movements of both projectors are used, and the "X" motion is used to control the scale. The former is more readily mastered and is quicker. It must be used on all but the first pair of a strip, and for short strips there is no objection to its use throughout. The beginner should learn it first. The latter has some advantage when starting a long strip, as "Z" and "Y" are not moved and thus the base of the first pair is maintained parallel to the bar; hence, if the flight line is nearly straight, the

mechanical limits of the "Z" and "Y" motions are not approached.

d. To move one projector only, note positions indicated in figures 31 and 32, and assume projector II only is moved:

(1) *Description of positions.*—Position 1 is near the principal point of projector II; position 2 is near the principal point of projector I on a line parallel to the bar through the principal point of projector II; positions 3 and 5 lie on a line perpendicular to the bar through position 1 an equal distance from position 1 and near the edge of the model; positions 4 and 6 lie on a line perpendicular to the bar through position 2 an equal distance from position 2 and near the edges of the model.

(2) *Procedure.*—Remove parallax by the following steps:

(*a*) At position 1 by "Y" motion.

(*b*) At position 2 by "Swing" motion.

(*c*) Repeat steps (*a*) and (*b*) until parallax is removed at positions 1 and 2.

(*d*) At position 5 by "Z" motion.

(*e*) At position 3 by "Tilt" motion; overtilt by an amount varying with the distance from the center, roughly equal to the amount of parallax, that is, introduce parallax in opposite direction equal to the original parallax. (For the normal projectors this overtilt should be about two and one-half times.)

NOTE.—If roughly one-third of the parallax at position 3 is removed by "Z" motion before step (*e*) is undertaken, the orientation time may be reduced, especially when the parallax at position 3 is great.

(*f*) At position 1 by "Y" motion to remove parallax created by (*e*).

(*g*) Repeat steps (*d*) to (*f*) until positions 1, 3, and 5 are free from parallax.

(*h*) Check position 2 for parallax and remove by "Swing" motion.

(*i*) At position 4 or 6 by "Tip" motion; after tipping from a position where the floating mark appears to be in contact with the ground, bring the floating mark again in contact with the ground by the "X" motion. (Because the major portion of the tip motion is in the "X" direction and parallax introduced in this direction will be evident as elevation displacement, the floating mark will seem to rise above the ground or sink below it when the tip motion is turned. The floating mark must be brought in contact with the ground again by means of the "X" motion.)

(*j*) Check for parallax at position 4 or 6 (whichever was not used in step (i)). If parallax is present, it means that one or more of the other positions are not free from parallax and the whole orientation procedure should be repeated. It is usually necessary to repeat this orientation procedure several times before all parallax is removed.

(*k*) Before assuming correct adjustment, recheck all six positions for parallax.

(3) For the first adjustments of parallax in a model, the above procedure should be followed exactly. When all large amounts of parallax have been removed, the fine parallax is more readily removed by analyzing its character. For instance, if positions 3, 5, and 6 are free from parallax, but there is a small amount at 4, position 2 should be examined carefully for an error in "Swing," since, if the model is otherwise correct, the parallax at 4 and 6 is equal and opposite (tip parallax). If parallax can be found in position 2 in the right direction and if there are no other errors, a correction of this by "Swing" will cause the parallax at 4 and 6 to be equal and opposite and removable by "Tip." Likewise, if when removing the "Tilt" and "Z" combination, as in steps (3) (*d*) to (*g*) above, the parallax in positions 3 and 5 is noticed to be equal and opposite, a "Z" correction only is indicated.

(4) Since it is desirable to have well-defined image points for the removal of parallax, and since it is not always possible to select good points in the small areas designated, it is sometimes necessary to go outside these positions for image points. In this case an allowance must be made in removing and analyzing the parallax for the actual location of the point.

(5) It is essential that the entire model be checked after any movement is made during

final accurate adjustment. Although the steps are so planned as to hold one part of the model correct while moving another, this is never absolutely true, especially so since the terrain points can seldom be chosen as indicated and tilt ordinarily keeps the plate perpendicular from coinciding with the perpendicular from projectors to table.

e. To use rotational movements of both projectors, note the same figures and description of positions as in *c* above.

(1) *Procedure.*—Remove parallax by the following steps:

(*a*) At position 1 by swing of projector I.

(*b*) At position 2 by swing of projector II.

(*c*) Repeat steps (*a*) and (*b*) until parallax is removed at positions 1 and 2.

(*d*) At position 5 by tip of projector I; after tipping from a position where the floating mark appears to be in contact with the ground, bring the float mark again in contact with the ground by the "X" movement, in order to maintain the approximate scale.

(*e*) At position 3 by tilt of projector I; overtilt by an amount varying with the distance from the center, roughly about one and one-half times the amount of parallax (introduce parallax in opposite direction equal to approximately one and one-half times original parallax), and remove the parallax at positions 1 and 2 by repeating steps (*a*) and (*b*). (For the normal projectors this overtilt should be about two and one-half times.)

(*f*) Repeat steps (*a*) to (*e*) until positions 1, 2, 3, and 5 are free from parallax.

(*g*) At position 4, or 6, by tip of projector II; after tipping from a position where the floating mark appears to be in contact with the ground, bring the floating mark again in contact with the ground by the "X" movement.

(*h*) Check for parallax at position 4 or 6, whichever was not used in step (*g*). If parallax is present, it means that one or more of the other positions are not free from parallax and the whole orientation procedure should be repeated. It is usually necessary to repeat this orientation procedure several times before all the fine parallax is removed.

(*i*) Before assuming correct adjustment, recheck all six positions for parallax.

39. ABSOLUTE ORIENTATION.—a.

Absolute orientation consists of giving the model a correct scale and horizontalization. The former requires at least two points known in position and the latter at least three known in elevation. They need not be the same points, but this is desirable as it provides a cross check and also helps in identification. More points are desirable.

b. Scaling.

(1) A plot containing at least two points known in position is placed on the table beneath the model. With the pencil of the tracing table over one of these points, the plot and tracing table are shifted until the floating mark is in contact with the same point on the terrain, the floating mark being raised or lowered as necessary. The plot is rotated about this point until the directions to the second point on both model and plot coincide. The second point is then examined to see whether its position is long or short of that on the plot. The scale of the model is then altered by shifting one of the projectors along the base line to enlarge or reduce the size of the model as necessary. If the base line is perfectly parallel to the bar, this is accomplished by an "X" movement of one of the projectors, as indicated diagrammatically in figure 33. As the base line is seldom truly parallel to the bar, it will in many cases be necessary to apply not only an "X" movement but also a "Y" and a "Z" movement to the projector. Whether or not this is necessary is indicated by an analysis of the small amounts of parallax which may be introduced in the model by the "X" movement. After altering the scale of the model an estimated amount, the two points are again checked and this procedure is repeated if necessary. When the scale of the model is reduced,

the height of the model above the table increases and when the scale of the model is enlarged, the height of the model above the table decreases. The tracing table platen must be raised or lowered accordingly. If the scale change is of such an amount that the model falls above or below the range of the tracing table, the height of the model must be altered by raising or lowering the bar.

c. Horizontalization.

(1) Horizontalizing a model necessarily is done in two steps: by tilting the model as a whole and by tipping the model as a whole. If the vertical control is well placed, that is, if the elevations are on a line perpendicular to the axis of rotation, the model can be horizontalized about that axis by rotating the model as a whole until the model elevations on that line agree with the ground elevations. However, if the vertical control is not perpendicular to the axis of rotation, which is usually the case, errors in elevation will have components perpendicular to both axes, and the amount of tilt and tip required will have to be determined by a trial and error procedure, tilting and tipping alternately until all model elevations agree with ground elevations

(2) For reading elevations in a model, a conversion table should be compiled (see fig. 34) for changing the ground elevation in feet to elevation in millimeters at the mapping scale. The following formula gives the millimeter equivalent of 1 foot of ground elevation:

$$1 \text{ ft.} = (304.8 \times R.F.) \text{ mm}$$

Example: For plotting at 1/20,000

$$1 \text{ ft.} = 304.8/20{,}000 = .01524\text{-mm}$$

Elevations of vertical control points should be recorded on the Multiplex sheet in terms of millimeter equivalents.

(3) In horizontalizing, the floating mark is set on the ground at one of the vertical control points, then the index of the tracing table vernier is set to agree with the correct elevation of that control point, and the elevations of the other control points are read. It is not always possible to set the index of the vernier exactly at the correct elevation due to its limited range of motion. In such cases, it is convenient to apply an index correction of an even multiple of 5. For example: suppose that the operator reads an elevation of 42.8 mm on a control point whose correct elevation

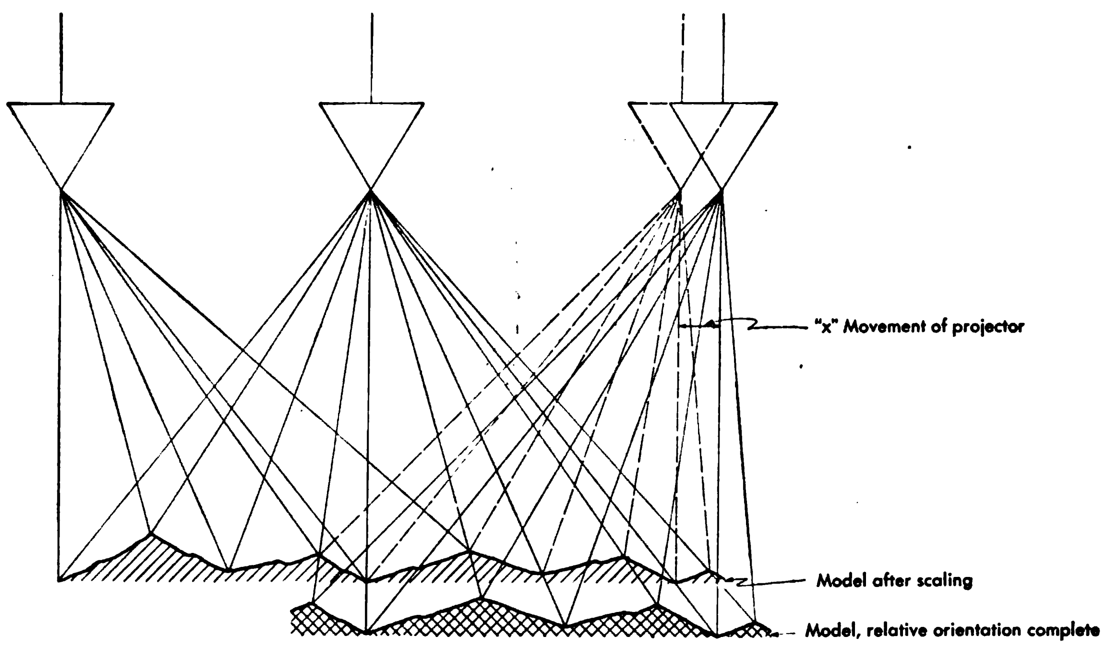

Figure 33.—Scaling the multiplex model.

at the scale being used is 10.3 mm. If the index setting is changed so that an elevation of 45.3 is read, then for all points in the model a correction of 35 mm must be subtracted from the elevation read in the model, to obtain the ground elevation. From the differences between the elevations read in the model

Interval 25 ft   1″=1333⅓ ft
(.01905004) Scale : 1–16,000

Elevation	Millimeters	Elevation	Millimeters	Elevation	Millimeters
1	0.02	400	7.62	1,400	26.67
2	.04	25	8.10	25	27.15
3	.06	50	.57	50	.62
4	.08	75	9.05	75	28.10
5	.10	500	.52	1,500	.58
6	.11	25	10.00	25	29.05
7	.13	50	.47	50	.53
8	.15	75	.95	75	30.00
9	.17	600	11.43	1,600	.48
10	.19	25	.91	25	.96
11	.21	50	12.38	50	31.43
12	.23	75	.86	75	.91
13	.25	700	13.34	1,700	32.38
14	.27	25	.81	25	.86
15	.29	50	14.29	50	33.34
16	.30	75	.76	75	.81
17	.32	800	15.24	1,800	34.29
18	.34	25	.71	25	.77
19	.36	50	16.19	50	35.24
20	.38	75	.67	75	.72
21	.40	900	17.14	1,900	36.20
22	.42	25	.62	25	.67
23	.44	50	18.10	50	37.15
24	.46	75	.57	75	.62
25	.48	1,000	19.05	2,000	38.10
......	......	25	.53	25	.58
50	.95	50	20.00	50	39.05
75	1.43	75	.48	75	.53
100	.90	1,100	.96	2,100	40.00
25	2.38	25	21.43	25	.48
50	.86	50	.91	50	.96
75	3.33	75	22.38	75	41.43
200	.81	1,200	.86	2,200	.91
25	4.29	25	23.34	25	42.39
50	.76	50	.81	50	.86
75	5.24	75	24.29	75	43.34
300	.71	1,300	.76	2,300	.82
25	6.19	25	25.24	25	44.29
50	6.66	50	.72	50	.77
75	7.14	75	26.19	75	45.24

Figure 34.—Conversion table of elevations feet to millimeters.

and the correct elevations for the various control points, the amount of tip and tilt necessary to bring the model to the proper level is estimated. The model is then horizontalized by tipping and tilting both projectors equal amounts, and the process is repeated until the elevations read in the model are the same as the correct elevation for the various control points. There are two methods of horizontalizing the model: the first, by using the projectors; the second, by using the bar.

(4) In horizontalizing by using the projectors, care must be taken that both projectors are tilted or tipped an equal amount. After deciding the direction that tilt must be applied, select an image point in the model and introduce parallax by tilting one of the projectors an estimated amount. Tilt the second projector until parallax at that point is removed. Check elevations and repeat the tilting process until elevations perpendicular to the axis of tilt agree with correct elevations. For horizontalizing in the tip direction, select an image point midway between the two principal points. With the floating mark on the ground, introduce parallax by tipping one of the projectors an estimated amount in the right direction. Tip the second projector until the floating mark again appears to be on the ground at the point selected. When both projectors are tipped, parallax is introduced in the model which may be removed by a "Z" movement. This in turn usually requires small amounts of "X" and "Y" movements. Check elevations and repeat the tipping process until elevations perpendicular to the axis of tip agree with correct elevations. Continue tilting and tipping the model as a whole until all elevations agree with the correct ground elevations, or until the errors are small and the method described in (5) below will not entail radical movements of the bar.

(5) Horizontalizing by means of the bar is a quicker and easier method to master. It is usually used for the final accurate horizontalization. To keep the bar from departing too much from level, elevations in the model should not differ by more than ± 0.5 mm from their true elevation before this horizontalization. This condition is attained in the

process of setting up the stereoscopic model, or by tilting and tipping both projectors as described in (4) above. The horizontalization is accomplished by means of the hand wheels and foot screws, as described in paragraph 20*c*.

40. EXTENSION OF CONTROL.—a. In all multiplex operations, the multiplex operator must be furnished sufficient information to scale and horizontalize his model. This information is determined by ground survey as far as conditions will permit. Since it is usually impossible and requires an excessive expenditure of time to obtain sufficient information by ground survey methods to control every multiplex model, ground surveys must be augmented by multiplex triangulation for the establishment of intermediate control information.

b. The extension of control refers to the case in which control information is concentrated on only a few photographs at the beginning of the strip, and the additional control must be established by means of a multiplex extension cantilevered from existing ground control. The extension of control involves the proper orientation, scaling, and horizontalization of a model or models, in which satisfactory minimum control information is available, and the joining of additional projectors to the models already formed until the complete strip of photographs has been assembled into a continuous stereoscopic model. If two projectors are set up as described in the preceding paragraphs, a third projector, containing a diapositive which overlaps one of the two may be added by the steps described in paragraph 38*c*. When relative orientation is perfected, it is only necessary to bring the new model to the same scale as the original by bringing points in the area common to both models to the same elevation by an adjustment of the "X" movement of the projector which has just been added (fig. 33). This being done, a fourth projector may be added to the third and the process repeated as often as necessary. In such an extension, red and blue-green filters will be used alternately in the projectors, making it necessary for the operator to reverse his spectacles in proceeding from model to model along the extension.

c. Instrumental, personal, and datum errors limit the practicability of extending control. Any extension decreases the accuracy of work; the longer the extension, the less the accuracy.

d. Preliminary.

(1) All ground control should be plotted on a stable medium (wood or equal composition) at the multiplex plotting scale. This plot should be large enough to cover the area to be mapped, or a suitable integral part of this area. Eventually it will contain all of the extended as well as the ground-determined control.

(2) Before starting an extension, contact prints of the strip should be assembled into a rough, shingle mosaic. This assemblage of photographs should be inspected and the mean line of flight determined. This is used in the initial alinement of the projectors upon the base bar of the multiplex frame so that the operator is assured that all projectors will remain within the limits of the "Y" motion of the projector. The angle made by the axis of the first photograph of the strip with the mean line of flight is determined.

(3) The pass points used by the Multiplex triangulation operators become the detailed control necessary to the plotters. They must be selected with the same care as ground control and under a stereoscope. One pass point must be selected as near as possible to the principal point of each photograph. Others must be selected at each edge of the photograph, on a line through the principal point

perpendicular to the flight line, preferably in the area of the side lap. These pass points must be identified and marked on all photographs in which they appear (adjacent flights also), and they must be visible in the preceding and following photographs. Occasionally alternate points must be selected to answer the requirements fully. A convenient method of designation consists of the number of the photograph, followed by a dash and a serial 1, 2, and 3 across the line of flight through the principal point. Alternate pass points may include the subscript "a".

(4) A strip of topographic acetate sheeting long enough to complete the Multiplex extension of this strip of photographs is furnished to the control extension operator. All available ground control must be plotted thereon in proper orientation to include the entire strip. As the operator proceeds along the extension, he plots all pass points with their elevations on this sheet.

e. Extension.

(1) The control extension operator first places all his diapositives in the projectors and obtains proper interior orientation and illumination. By means of the projector level the first projector is swung so that its diapositive is alined in the projector at the same angle determined in *d*(1) above for the angle between the axis of the first photograph and the mean line of flight. The first projector is usually set with both its "X" and "Z" movements in the middle of their range as a first approximation. However, if, because of the position of the strip with respect to the mean line of flight, a better approximation of the "Y" movement can be made, this should be used. All projectors are then roughly relatively oriented to insure further that all projectors remain within the limits of the "Y" and "Z" motion. If, because of an erroneous assumption in regard to the position of the "Y" and "Z" slides of the first projector, the extension cannot be kept within the limits of the movements of the projectors, another approximation of the position of the "Y" and "Z" slides of the first projector is necessary, and the rough triangulation is repeated.

(2) All initial models containing ground control are then carefully oriented to this control. This is extremely important, especially regarding horizontal control, which directly affects the accuracy of the extension.

(3) Projectors along the strip must be oriented successively, extreme care being taken to remove parallax and to retain the elevation of the center pass point in the succeeding model. No attention should be paid to anything else, as the accuracy of horizontal extension is entirely dependent on these factors, plus the control of the starting models. The positions and elevations of all pass points should be recorded on the extension sheet as the extension progresses. When the strip has been completed in this fashion, the positions determined are accepted if it is a single-strip extension, or are ready for adjustment if other strips are available.

(4) Upon completion of the horizontal extension, vertical extended elevations may be evaluated. However, these elevations must first be adjusted because of the curved datum which is usually evident by looking down a line of extended projectors. (See par. 63*b*.) In order to make an adjustment, it is assumed that the flight altitude of the strip was constant. The height of each projector (height of the projector boss from a fixed reference datum) is measured, and the difference in height of each projector boss (BZ) from the height of the second projector is plotted as ordinate against the horizontal distance from the second projector to each respective projector as abscissa. Through these plotted points a smooth curve is drawn. The departure of this smooth curve from the horizontal (level flight) may then be applied as a direct correction to the elevations of any point in the extension, as shown in figure 35. Since the projector boss indicates the projector height only when the "Y" slide of the projector is level, a correction must be applied to the BZ of each projector whose "Y" slide is sloped. This correction is equal to about one-third the difference in height between the extremities of the "Y" slide. Obviously, where the slope of the slide is the same in a bank of projectors, no correction is necessary for the purpose of constructing the "BZ" curve. If recorded altitudes, such as are obtained in the T-5 camera, are available, the difference in height of each projector from the second projector

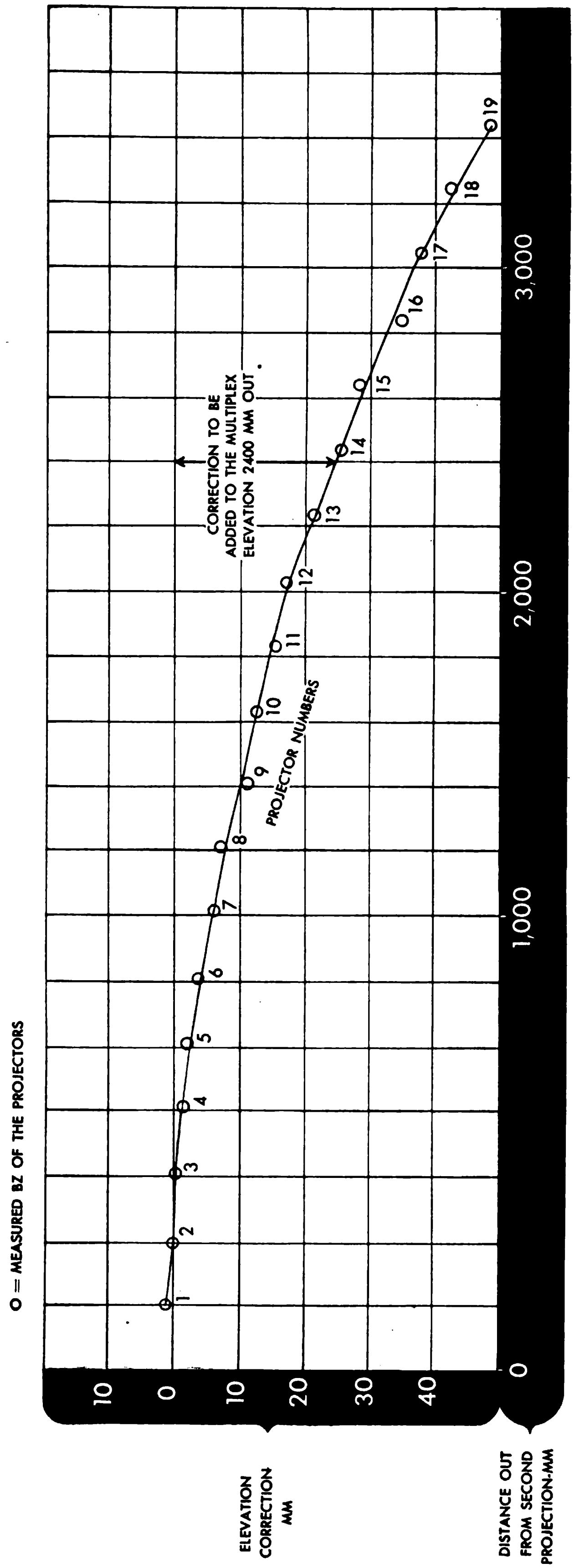

Figure 35.—Typical BZ curve used to adjust the elevations of a single strip.

should be adjusted by these data so that the points, plotted on the correction chart and through which the smooth curve is drawn, are referenced to a constant flight altitude. If P is the measured projection distance of the second projector in millimeters, Pn is the measured projection distance of the *Nth* projector in millimeters, H is the recorded altitude of the photograph in the second projector at the scale of the model, and H_n is the recorded altitude of the photograph in the *Nth* projector at the scale of the model, then the BZ to be plotted for the *Nth* projector is equal to:

$$(P-P_n)-(H-H_n)$$

(5) Elevations of side pass points are recorded during the extension as read from both the preceding and the following model. During the extension these readings should be carefully watched as a check on the accuracy of orientation. When cross tilt (par. 67) is present, the average of the elevations read from the two models is assigned to the side pass point before adjustment by the "BZ" correction curve.

(6) In the adjustment of elevations within a strip, terrain features also should be considered. Flat plains, lakes, bodies of water, and the direction of flow and the estimated slope of streams, can be used in such an adjustment. Adjustment of the strip to such terrain features should be made last. Intermediate elevations between such terrain features should be adjusted proportionately.

f. Adjustment.—When two or more strips are being extended, an adjustment between these strips is necessary. Only logical and simple adjustments should be made. Intricate analysis of theoretical possible errors are not worth while. The following rules are considered logical:

(1) Two short intersecting or parallel flight lines extended from control should receive straight line adjustments of position discrepancies without regard to other factors.

(2) Weights should be applied to adjustments of intersecting or parallel strips in inverse proportion to the distance extended from control in each strip.

(3) Where conditions permit, horizontal adjustments should be made by superimposing the extension sheets on the control plot. Once adjusted the positions may be pricked through to the control plot for use of the operators.

(4) Vertical adjustments should be performed analytically. An exception occurs when horizontalization to terrain features is made.

(5) The relative positions and elevations of points falling in a single model should be maintained as closely as possible in the adjustment.

g. Adjustment of positions between parallel strips.

(1) The simplest method of adjustment between parallel strips is to lay one strip over the other, matching the corresponding grid lines and pricking the mean position of points common to both strips. This will probably prove satisfactory if the deviation of the strips from the mean is small and of such a nature that relative positions within individual models can be maintained. However, the deviation from the mean in long extensions (for example, 40 miles at 1:20,000 scale) will probably be too large to permit such an adjustment.

(2) When the method described in (1) above disturbs the relative positions of points within a single model to a great extent, a combined graphical-analytical solution may be used. In this adjustment, all strips are given equal weight as to azimuth and scale. The differences in position of both the azimuth and scale components between adjacent strips are determined by scaling common points at intervals of about 500 mm along the strip. These differences are referred to the center strip, or any one strip of a group of parallel strips. Thus, in an extension of five strips the difference in the scale component (X coordinate) between strip 3 (center strip) and strip 2, added algebraically to the difference in the scale component between strips 2 and 1 at the same distance out from the base control, gives the scale error at that distance

between strips 3 and 1. Similar measurements made of the azimuth components (*Y* coordinates) are used to determine the error in azimuth. The deviation in scale for each of the several strips from the central one is then plotted as a series of curves on the same coordinate system (fig. 36). An average of these curves is then plotted on the same coordinates. The scale error of any point in the extension is then determined by scaling the difference between the scale deviation curve, for the strip in which the point occurs, and the average curve. This difference is then applied as a correction to the position of the point as plotted from the extension. A similar procedure is used to determine the azimuth correction for each point. Where the flights are laid out parallel to the grid system used in the plotting, the scale and azimuth deviation between strips may be determined with respect to this coordinate system. Where the flights are skewed with respect to the grid lines, an arbitrary coordinate system must be established in which the *X* or scale coordinate is parallel to the mean direction of flight and the *Y* or azimuth coordinate is perpendicular thereto. Where a number of parallel strips are extended simultaneously, an adjustment by this method may be made within such a group of strips as rapidly as progress is made along the strips in the extension, and the compilation of detail may begin within a short time after the extension has started.

h. Adjustment of elevations between parallel strips.—After the extended elevations in each of the single strips have been evaluated (*e*(4), (5), and (6) above), an adjustment between strips is made by averaging the elevations of those points which are common to two strips. Elevations not in the sidelap area are adjusted proportionately.

41. BRIDGING.—a. Bridging is a special case of control extension wherein control exists at each end of a strip, so that an adjustment to that control may be made. The multiplex operations are identical with those outlined in paragraph 40 for the extension of control.

b. The adjustment of positions in a bridge section may be accomplished most readily by adjusting the scale of the multiplex strip and by orienting the acetate sheet containing the control to the position which gives the best average correspondence between the points in the models and those plotted on the sheet. As indicated in figure 33, when the scale of a model is altered by an "X" movement of one of the projectors forming the model, the height of the model above the multiplex table is changed. This relationship between the change in height of the model and change in scale may be used to adjust the scale of a strip. The amount by which the height of the model must be altered to correct an error in scale is the percentage of error in scale multiplied by the projection distance. The height of the first model of the strip is altered by the amount necessary by an "X" movement of the second projector of the strip, and the other models of the strip are scaled successively to the preceding model by making the elevations of the center pass points the same. If the proper scale is not attained on the first trial, this is repeated.

c. The adjustment of elevations in a bridged section is accomplished in the same way as for the extension, except that in this case the correction to be applied at the end of the section will be known from the error in closure. The difference between this known elevation correction and the correction from the "BZ" curve is applied proportionally back through the strip as a straight line adjustment. The information necessary to make these elevation adjustments should be obtained

from the original extension before the strip is scaled, provided the error in scale is not over about 0.3 percent.

42. PLOTTING.—a. After the necessary control has been established, each operator is furnished one of the diapositives he is to plot, a contact print of each photograph upon which all control is plainly marked, and a plotting sheet on which all control is plotted and all elevations are indicated. Certain grid intersections are also shown for ease in subsequent orientation. Where the operator must join work previously completed, it is often advisable to trace borders of adjacent sheets on the plotting sheet so that he may make the necessary junction at once.

b. After each model is scaled and horizontalized to the established control plotting is commenced. The contours are ordinarily plotted first. The table of millimeter settings for elevations at the scale used is consulted and a contour falling within the model is selected. The tracing table is set for this height and clamped. The floating mark is then placed in contact with the model, the pencil lowered, and the contour traced by keeping the mark in contact with the ground. In terrain that is difficult to interpret (wooded areas, steep slopes, flat valleys), it is well to put in several adjacent contours and also to inspect the drainage before accepting any contour as a whole.

c. Following the plotting of contours, the planimetry is plotted. The floating mark is placed on a planimetric feature, the pencil lowered, and its slope followed with the floating mark, care being taken to keep the mark in "contact" with the feature. The tracing table reading light should be turned on at intervals to insure proper recording by the pencil point. On most mediums it is necessary to trace over these lines to emphasize them. Some difficulty may be experienced in following roads or streams through woods. To aid in determining the proper course, contact prints should be viewed through a hand stereoscope.

d. Other information desired can then be added, such as spot elevations of certain terrain features, woods, etc.

e. Considerable time may be saved in the plotting operation if the work is planned and the equipment is available, so that the plotting of planimetry may be performed from bridged sections. In these instances the planimetry is plotted first, with the bridged section approximately horizontalized. After the planimetry has been compiled, each model is horizontalized individually and the contours are drawn.

f. Where an operator has only two projectors available and is plotting a strip, advantage should be taken of the fact that one of the projectors forming the model just completed is in very nearly the correct orientation for the adjacent model. By "leapfrogging" the projectors the orientation of this one projector is not disturbed and the orientation time for the next model may be thus reduced.

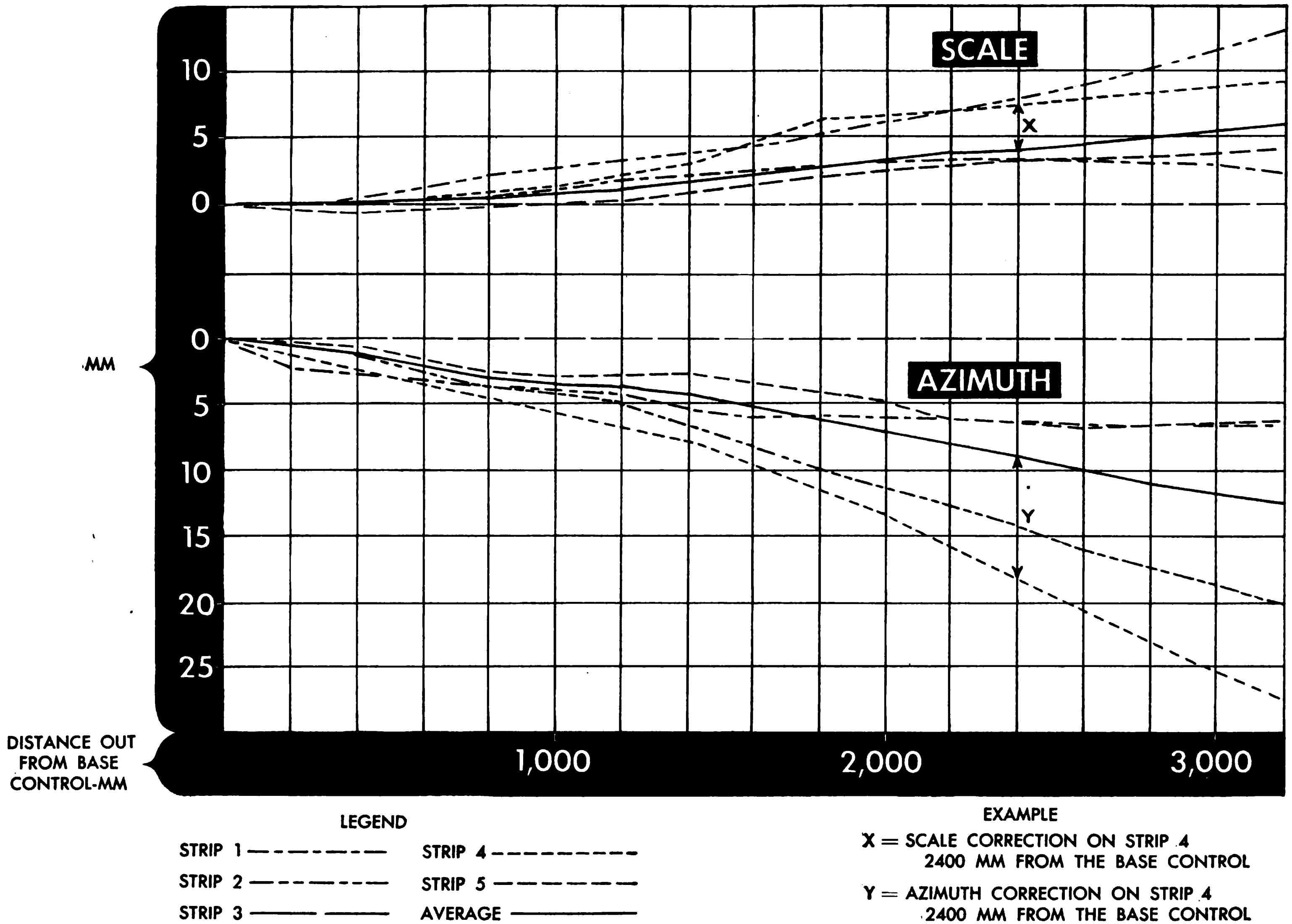

Figure 36.—Typical curves used in adjusting the scale and azimuth of a five-strip extension.

SECTION V

PREPARATION OF DIAPOSITIVES

43. GENERAL.—**a.** As the success of the multiplex operation depends largely on the quality of the diapositives, utmost care must be taken in their preparation. The accuracy of the final multiplex product can be affected and the time necessary for its completion can be greatly increased through poor photo technique or improper handling of the diapositive plates in the process of preparation.

b. The photographer should thoroughly familiarize himself with the construction and special precautions necessary in the use of the reduction printer. (See pars. 28 and 29.)

44. EQUIPMENT.—The equipment necessary for making diapositives consists of the following:

a. Reduction printer.

(1) Wide-angle printer for 6-inch, K–17, K–3B, or T–5 negatives.
(2) Type I for 6-inch, T–3A negatives.
(3) Type II for 8¼-inch, K–3B negatives.

b. Photographic trays for developing, fixing, and washing.

c. Provision for drying.

d. Thermometer.

e. Interval timer.

f. Continuous timer.

g. Exposure meter (desirable but not necessary).

45. THE DIAPOSITIVE PLATE.—The diapositive plates should be of the best quality obtainable, having an emulsion of relatively fine grain which does not creep nor peel. They are procurable commercially as plates, diapositive, coated with lantern slide emulsion with nonhalation backing on specially selected flat glass 0.05 inch thick. For the wide-angle projectors the diapositive size is 54 by 54 mm +0.8, −0.2 mm; for the normal projectors the size is 46 by 54 mm +0.8, −0.2 mm. Contrast No. 3 plate can be used with practically all aerial negatives.

46. PHOTOGRAPHIC SOLUTIONS.—**a.** In course of time the photographer is required to prepare plates from all types of film: of strong or weak contrast; of high or low average density. No one developing agent is uniformly success-

ful in all cases. The photographer must bear this in mind and strive to standardize, for his own use, developers and developing technique for each type of film. In all cases, the developer should be of a type that will not reduce the resolving power of the emulsion. Since only one contrast of diapositive plate is generally used, the desired contrast in the diapositive must be obtained by varying either the developer or the development time. The first method is recommended, however. It has been found that with extremely flat negatives, D-72, a standard Eastman Kodak Company formula, used full strength, gives the best result. With an average negative, D-72 mixed 1:1 gives satisfactory results. When contrasty negatives are used, D-72 developer should be diluted until the diapositive plate has the proper contrast. The normal development time with this developer is about 3 minutes. In some cases where an extremely contrasty negative is used, it is necessary to dilute the developer as much as 1:12 to obtain the proper contrast in the diapositive. D-76, another Eastman Kodak Company formula, is also recommended, and variations in contrasts of diapositives can be obtained by dilution of this developer. Normal development time for this developer is about 20 minutes.

b. The formulae for these developing solutions are as follows:

Metol—hydroquinone developer.

D–72

Water (about 125° F.)	96 ounces.
Mono-methyl-paraminophenol sulfate (elon or metol).	11.7 grams.
Sodium sulphite	170.1 grams.
Hydroquinone	45.4 grams.
Sodium carbonate	295.0 grams.
Potassium bromide	7.0 grams.
Add cold water to make	1 gallon.

Full strength for extremely flat negatives.
Mix 1:1 for normal negatives.
Dilute for negatives with strong contrast.
Use at 65° F.

Metol—hydroquinone—borax developer.

D–76

Water (about 125° F.)	96 ounces.
Mono-methyl-paraminophenol sulfate (elon or metol)	7.6 grams.
Sodium sulphite	380.0 grams.
Hydroquinone	19.0 grams.
Borax (sodium borate)	7.6 grams.
Add cold water to make	1 gallon.

Full strength for normal negatives.
Dilute for negatives with strong contrast.
Use at 65° F.

c. The fixing bath should be of the following standard formula:

Water (about 125° F.)	96 ounces.
Sodium thiosulphite (Hypo)	32 ounces.
Sodium sulphite	2 ounces.
Acetic acid (28 percent pure).	6 ounces.
Boric acid (crystals)	2 ounces.
Potassium alum	2 ounces.
Add cold water to make	1 gallon.

47. SETTING REDUCTION RATIO.—a. As described in paragraph 28*c*, the wide-angle reduction printer is equipped with a variable reduction ratio. Before printing diapositives both knurled rings must be set at the focal length of the camera with which the photography was performed, in order that the printer will be in focus and the diapositive will have the correct principal distance for use in the projectors. Both rings are always set at the same figure. When photography has been performed with the 6-inch K–3B or K–17 camera, the focal length, in millimeters, should be requested from the agency performing

the photography. The focal length is stamped on the lens mounting ring of these cameras. When photography has been performed with the T-5 camera, the focal length, in millimeters, will appear on the data card, which is one of the recordings registered on the film.

b. Since the normal reduction printers, both type I and type II, are not equipped with a variable reduction ratio, no such setting for the individual focal length of the camera can be made.

48. ORIENTING THE NEGATIVE IN THE REDUCTION PRINTER.—In order to place the negative in the printer, remove the dome and upper pressure plate and examine the surfaces of the pressure plates to see that they are clean and free from dust. The film may be cleaned with carbon tetrachloride if necessary. Engage the film spool in one bracket, draw the film, emulsion down, across the lower pressure plate, and attach to an empty spool in the other bracket. Then replace the upper pressure plate and the dome. The proper interior orientation is obtained by alining the fiducial marks of the film with the collimating lines on the lower pressure plate. This alinement is made while the photographer is observing the negative and collimating marks on the lower pressure plate through the viewing windows in the dome. To do this, raise slightly the upper pressure plate by the foot treadle until the film, though held firmly, may be moved about between the pressure plates without any undue strain. Aline the collimating marks with their corresponding lines, then release the upper pressure plate to clamp the film. A final check of the alinement must be made after clamping. It may be necessary to adjust the negative several times before absolute coincidence is attained between the fiducial marks on the film and the collimating lines on the lower pressure plate. At times it may be found impossible to bring all four fiducial marks into absolute coincidence with the collimating lines, or dirt may have lodged in a fiducial mark in the camera so that the mark is somewhat obscured. In such instances, it is best to use only three marks for the orientation and to be consistent in using these same three marks in orienting all of the negatives in the flight.

49. ILLUMINATION.—**a.** Generally, all aerial photographic negatives are more strongly exposed in the center than in the corners. Inspection of the film will give the photographer an idea of the density difference throughout the exposure in question.

b. Since it is desirable to have diapositives of uniform density throughout, the intensity of the light projected through the center of such a negative must be greater than that projected through the corners. As an aid in accomplishing this, the printer is equipped with a compensating lens. By raising the compensator to the top of its travel, the minimum intensity of light in the corner is obtained. An experienced operator can judge by examining the negative where the compensator should be set for best results. For the beginner a few trial exposures at various settings of the compensator will indicate which should be used.

c. After the best setting of the compensator is determined, if the diapositives still have an uneven density, it may be necessary to adjust the position of the light bulb. The bulb may be

raised, lowered, or shifted about the center to a position giving best results.

d. Other variations in density (due to the altitude of the sun at exposure, variations in the type of terrain depicted, or other causes) cannot be compensated for with the compensator lens, as it has a limited range and can only compensate for the annular change in density from the center of the negative. These irregularities can be compensated for only by proper shading or dodging. This is a difficult task and only practice will enable the photographer to dodge successfully. Dodging disks may be inserted between the lower pressure plate and the diffusing glass through the slot provided on the side of the printer.

e. When necessary to make diapositives from a considerable number of negatives with like variations in density, it may be advisable to make a diffusing mask of some partially opaque material, such as tracing cloth, tracing paper, or sheet acetate, to be inserted in the printer. This may be made by starting with a single sheet of the material for those portions which need no shading and shingling up to a maximum thickness over those portions which need the most shading by adding successively sheets of smaller size.

50. EXPOSURE AND PROCESSING.— **a.** A good diapositive is free from streaks, marks, or other blemishes and may have the appearance of a soft pencil sketch. In general, a usable plate looks weak to the eye with transmitted light. The finest detail of the terrain, including that in the deepest shadow as well as the strongest highlight, must be recorded while holding the contrast to a minimum. A diapositive of more contrast than is needed is unsatisfactory. It is essential that all diapositives be of the same average contrast and density; otherwise, the multiplex operator is forced to vary the illumination of his projectors continually.

b. In general, any one roll of film has similar contrasts in each negative, but the densities may vary. This may require a different exposure time for each negative in extreme cases in order to get uniform diapositives. An experienced photographer is able to judge closely the proper exposure, developer, and development time, but where experience with a similar type negative is lacking, trial exposures must be made to determine the proper treatment. If the trial exposures are made of those negatives having the highest and lowest densities, the exposure time for other negatives in the strip may be determined by using an exposure meter.

c. To use the exposure meter, remove the dome from the printer and place the meter on the center of the pressure plate. Raise the upper pressure plate by means of the foot treadle and run the film through the printer, recording the meter readings at the center of each negative. By interpolating between the exposure times found by trial for the negatives of highest and lowest densities in direct proportion to the change in meter readings, the exposure times for all other negatives may be determined.

d. When ready to expose the diapositive plate, extinguish all white light and use only the red safe light recommended by the diapositive manufacturer. Secure an unexposed plate and remove all particles of dust and lint by tapping the plate lightly on its

edge. Place the diapositive, emulsion down, on the diapositive stage and press it firmly against the stops provided on one end and one side of the stage opening. While holding it in this position, place the clips over the diapositive to hold it in place while the exposure is made. A felt-covered weight about the size of the diapositive and weighing approximately ½ pound may be used instead of the clips. It is extremely important that the diapositive be in perfect contact with the stage. Expose the plate by turning on the light in the printer. After proper exposure extinguish the light and carefully remove the plate, holding it with the thumb and fingers in contact with edge of the plate. The diapositive is then ready to be developed.

e. The plate should be fully developed in accurately mixed developer held to the correct temperature. Time may be conserved by developing several plates simultaneously.

f. After developing, the plate must be thoroughly rinsed in clear running water at 65° F. and then fixed for 10 minutes. The fixing bath should be freshly mixed, free of impurities, and of the same temperature as the developer. After fixing, the plate must be washed in clear, cool, running water for about 30 minutes. In washing, it is necessary that the water be absolutely clean. If there is sediment present, it may scratch or adhere to the plate, a feature not always rendering the plate useless, but causing the multiplex operator considerable annoyance.

g. Best results are obtained by drying the plates as rapidly as possible in a flat position. Grain or denatured alcohol is used to speed the drying process. Wood alcohol should not be used because of its injurious effect on personnel. After washing, immerse and agitate the plates in alcohol for 60 seconds. Remove from the alcohol and allow all surplus alcohol to drain off to one corner. At this point it is permissible, where necessary, to swab the emulsion very lightly with a cotton swab saturated in alcohol. At no other time should the emulsion be touched. Then place the diapositive, emulsion side up, on the table or a piece of cardboard for drying. Drying diapositives placed vertically on a rack is not recommended.

h. The photographer must constantly realize the necessity for handling the plates with extreme care. Minute displacements introduced in the emulsion by improper handling cause distortion to occur in the multiplex model which make it impossible to remove all parallax and cause elevations to be in error. If the water for washing is clean and the hypo and developer are fresh and free from impurities, there is no necessity for swabbing the emulsion side of the plate.

i. It is a recognized fact that a photographer who has had some experience as a multiplex operator is better able to produce good plates as a result of that experience. A limited amount of training in multiplex operation is therefore recommended for photographers.

SECTION VI

MULTIPLEX ACCURACY

51. GENERAL.—a. In topographic mapping, accuracy requirements for vertical heights are normally more stringent than those for horizontal positions. For example, a 1/20,000 map with 20-foot contours usually allows a vertical error of 10 feet and a horizontal error of 33 feet. In multiplex mapping, the intersection angles of corresponding rays are such that vertical locations are less definite than horizontal locations. For these reasons the vertical multiplex error is more critical, and in a single model, if the usually required vertical accuracy is obtained, the horizontal accuracy presents no problem. When the ground control is such that multiplex triangulation is necessary, the horizontal accuracy in triangulated positions must be considered.

b. Factors that affect the accuracy of the multiplex method of mapping are the multiplex equipment, the aerial camera, the photographic materials, the base-altitude ratio, the character of the terrain, the character of the control, the character of the photography, and the ability of the operator. Some of these factors are rather definite, while others vary so greatly that they can only be estimated for a particular project. In the following paragraphs each of these factors is discussed and the probable net result under ordinary conditions is estimated.

52. MULTIPLEX AND GROUND ACCURACY.—a. Units of measurement.— A multiplex model is a reconstitution to scale of a portion of the earth's surface and of the taking positions of the aerial camera. The accuracy of this scaled model can best be discussed in terms of measurements in the model, such measurements being conventionally stated in millimeters. These measurements can then be converted to actual ground distances for any particular model by reference to the scale of that model.

b. Altitude and projection distance.— In the multiplex model the projection distance represents the flight altitude. As the projection distance is reasonably constant in all multiplex models, it comprises a convenient common reference for ground and model accuracy. A model error is a certain fraction of the projection distance and is therefore the

same fraction of the flight altitude expressed in the units of ground measurement. Thus, the normal projection distance being 360 mm, a model error of 1 mm is 1/360 of the projection distance and represents a ground error of 1/360 of the flight altitude.

c. Selection of altitude.—The maximum flight altitude that gives the required accuracy is most economical. If the multiplex model accuracy can be estimated, the maximum flight altitude to obtain the required ground accuracy can be determined by simple proportion. For example, a ground accuracy of 20 feet vertically from multiplex models, accurate vertically to 1/500 of the flight altitude, can be obtained from the following altitude:

$$1/500 = 20/\text{altitude}, \quad \text{altitude} = 20 \times 500 = 10{,}000 \text{ ft.}$$

53. ACCURACY OF THE MULTIPLEX EQUIPMENT.

a. Wide-angle projectors.—The wide-angle projectors are required to project identical grids to form a flat stereoscopic model when properly oriented to within ±0.15 mm. The projectors meet this requirement and, within the portion ordinarily used with 60 percent overlap, they approach an accuracy of ±0.05 mm. The principal distance of the projectors is required to be within ±0.1 percent of the theoretical value of 28.182 mm. The foot of the perpendicular from the node of the lens to the stage glass is marked at least to within 0.02 mm. The stage plates are flat enough to cause no measurable error in the projection. An elevation error less than ±0.15 mm may be attributed to the wide-angle projectors.

b. Normal projectors.—The normal multiplex projectors are required to project identical grids to form a flat stereoscopic model to within ±0.1 mm. The projectors meet this requirement, and, within the portion ordinarily used with 60 percent overlap, they are usually better. Principal distances of the projectors match the nominal value of the 46.04 mm within 0.1 mm. The foot of the perpendicular from the lens node to the stage plate is accurately marked at least to within 0.02 mm. The stage plates are flat enough to cause no measurable error in the projection. An elevation error less than ±0.1 mm may be attributed to the normal projectors.

c. The wide-angle reduction printer.—The wide-angle reduction printer has distortion characteristics which compensate for the distortion in the 6-inch Metrogon lens so far as possible and still maintain sufficient resolution in the diapositive plane. The distortion characteristics of the camera lenses, as well as the printer lenses, vary somewhat from the nominal so that the same degree of compensation is not realized in all cases; however, model errors introduced by this factor probably will not exceed ±0.1 mm. The reduction ratio of the printer may be adjusted to take care of variations in the focal lengths of the cameras.

d. The normal reduction printer.—The normal reduction printers have lens distortions of approximately 1/3000. Occasionally they have tilts between the negative and diapositive planes of about 1/2000. These tolerances in themselves are negligible when compared to other errors. The reduction factor of the printer is fixed and is based on the average camera focal length and the average projector focal length. (See par. 54*b*.)

e. Resolving power of wide-angle equipment.—The limitations of the wide-angle multiplex equipment in respect to its resolving power should be realized. Because the equipment is designed to give the best compromise between distortion and resolving power, some sacrifice of resolving power is necessary. In addition, in order to satisfy the requirements in regard to size and ease of operation, a greater reduction in the printer and a greater enlargement in the projectors, as compared to the normal equipment, is necessary. For these reasons, the resolving power in the wide-angle equipment is not as good as in the normal equipment. However, the clarity of image is such that, together with the increased accuracy of the equipment due to other factors discussed, no decrease in accuracy from this cause can be expected.

54. ACCURACY OF AERIAL CAMERA.—a. Wide-angle camera.

(1) Two types of cameras are used in conjunction with the wide-angle multiplex equipment, the K–3B or K–17 and the T–5. Both are equipped with 6-inch Metrogon lenses.

(2) The distortion in the lens in the K–3B or K–17 is specified not to exceed one part in 500, measured from the center of the negative, and the distortion in the lens in the T–5 is specified not to exceed one part in 750. This distortion is compensated for in the reduction printer. (See par. 53*c*.)

(3) The variations in focal length between cameras is compensated for in the reduction printer.

(4) The specification for the T–5 camera requires that the fiducial marks shall indicate the position of the optical axis correctly within ± 0.0005 inch and that the focal plane shall be perpendicular to the optical axis within ± 1 minute of arc. The fiducial marks thus indicate the principal point within 0.003 inch. As the K–3B or K–17 camera has the focal plane in a detachable magazine, the accuracy of the T–5 camera is not attained in all K–3B and K–17 cameras. However, since a constant error in the principal point is not as serious as a variable error, this factor does not noticeably affect the single multiplex model. The movement between successive exposures of an ill-fitting magazine with respect to the K–3B or K–17 camera body is a far more serious error.

b. Normal cameras.

(1) Two types of cameras are used with the normal multiplex equipment: the T–3A and the 8¼-inch K–3B.

(2) The distortion in the T–3A lenses seldom exceeds one part in 1,500. This distortion can cause a warpage of $\pm$ 0.1 mm in the multiplex model. Some of the lenses used in the 8¼-inch cameras have rather large distortion characteristics which could cause warpage in the model greater than $\pm$ 0.1 mm. If there is a doubt as to the accuracy of a lens, it is advisable to have its distortion characteristics checked, or a check may be made by reading the multiplex elevations in a well-controlled model.

(3) Variations in focal length cannot be compensated for in the normal reduction printers. The type I reduction printer is set to give the proper reduction for a camera of 149.7-mm focal length while the type II printer is set to give the proper reduction for a camera of 210-mm focal length. Focal lengths which deviate from this average will not be correctly reduced in these printers to the focal length of the projector. In the T–3A cameras the deviation from this average is considerable, the worst case (camera 31–76) having a focal length of 148.6 mm, a deviation of 1.1 mm. Fortunately, the resultant model error is small. With no tilt, the vertical scale differs from the horizontal scale in proportion to the error in reduction. This is usually negligible, being noticeable only when there is a great amount of relief above or below the control points. When tilt is present, a warpage of the model results, varying with the amount of tilt, the amount of relief, and the error in reduction. For single models this warpage error may be disregarded.

(4) In T–3A cameras, the principal point is located within 0.001 inch, a tolerance consistent with printers and projectors. The K–3B cameras, which have the focal plane in a detachable magazine, require careful calibration to insure recovery of the principal point. Fiducial marks are required to be clear-cut and must be on perpendiculars in order to match the printer collimating lines, this requirement being as important as the actual location.

c. Vacuum.—All Army Air Forces mapping cameras hold the film in the focal plane by a vacuum system. Failure of this vacuum system renders the photograph useless for multiplex work. Inability to remove parallax from the models may be a sign that this has happened.

55. ACCURACY OF PHOTOGRAPHIC MATERIALS.—a. Aerial film.—Uniform shrinkage of aerial film has the effect of varying the camera focal length. If deemed necessary, this can be compensated for by correcting the reduction ratio of the wide-angle reduction printer accordingly. With modern topographic film base this effect is much less than that described in paragraph 54*b*(3). Nonuniform shrinkage is undesirable but is present in only insignificant amounts in good topographic film. Care in processing, handling, and storing negatives is essential. Properly handled, topographic film should not cause noticeable errors in the projection.

b. Diapositives.—Diapositive plates are of specially selected glass, flat enough to eliminate readable errors in the model. However, plates which "rock," or do not make good contact with the stage plate, should be discarded. The most probable source of diapositive error is that due to processing. Touching or rubbing the emulsion when wet will inevitably warp the image. A small local distortion (for example, 0.01-mm) may easily cause a 0.1-mm model error because of the enlargement in the projectors. Another error is caused by improper alinement of the negative in the reduction printer. A small error may be tolerated if it is uniform in all diapositives. The film roll should be passed through in only one direction and the alinement should be accurate to about ±0.1 mm in the negative plane. Careless alinement, especially on terrain of great relief, may cause large model errors.

56. THE BASE-ALTITUDE RATIO.—Given equal conditions, an increase in the ratio of the air base to the flight height decreases the model error in the heights of features; it increases the accuracy of relative orientation, reduces the deformation in the model, and makes stereoscopic perception stronger. Thus with any particular camera-printer-projector combination, photography with 50 percent overlap should give twice the vertical accuracy as photography with 75 percent overlap. This statement should be used with caution when comparing different cameras or multiplex equipment, as this increase in accuracy applies directly only when other things are equal, since the base-altitude ratio is only one factor affecting accuracy. For instance, a K–3B camera having rather poor distortion characteristics gives a poorer model than a T–3A camera even though the base-altitude ratio is more favorable.

57. CHARACTER OF THE TERRAIN.—As in all mapping, the character of the terrain affects multiplex accuracy to a great extent. The following considerations apply:

a. Contrast.—Accuracy of stereoscopic perception is directly affected by the contrast of the image viewed. It would be impossible to form a stereoscopic model, or to make measurements thereon, if absolutely no contrast existed in the diapositives. Fortunately, natural conditions and modern photography have helped. However, there are many areas where the problem is hard to solve. In general such areas are of two classes: Those with too little, and those with too much contrast. Flat grasslands, alkali flats, and barren beaches or river bottoms have too little contrast. Bordering detail helps orientation, but measurement is always difficult. High-altitude photographs of wooded areas with a large percentage of clearings have too much contrast; it is then difficult to retain the photographic detail in the light areas without destroying it in the darker areas, or vice versa. Diapositive contrasts and projector illumination can be varied to help solve this problem.

b. Woods.—Dense woods obscure the terrain. Three partial solutions are available. If numerous clearings are available, a combination of logical and continuous contouring can be used. Extremely dense woods offer the possibility of measuring their mean height, applying a correction, and contouring the tops. In many areas, photography can be planned when the trees are leafless.

c. Water.—It is impossible without special simultaneous photography to obtain stereoscopic models over water. This, in effect, reduces the working area of the model and in turn reduces accuracy. Where water areas are great, they must be considered in planning the photography.

d. Relief.—Great relief normally offers no special problem as long as the ratio of relief to altitude is less than the ratio of usable projection distance to total projection distance. Special cases arise where steep slopes are masked, in which case special flight lines may be necessary. A combination of great relief and large tilts brings certain types of errors to their maximum effect on the model, but in any case the error is small. In the case of the normal equipment, an adjustment of the vertical scale for an improper reduction factor may be made but is probably an unnecessary refinement.

e. Flat areas.—When the total amount of relief in a model is within or near the probable accuracy of mapping, the resultant contours are difficult to draw and may be displaced by large amounts. In production of military maps this is not of critical importance since the required vertical accuracy can still be held. Certain maps for various engineering purposes require a more accurate solution of the drainage and contours.

58. CHARACTER OF CONTROL.—a. General.—A multiplex model can be no more accurate than the control to which it is scaled and horizontalized. The following considerations apply to the selection of control:

b. Horizontal control.

(1) The amount of horizontal control used will depend upon the general situation. The greater the density of this control, the greater will be the horizontal accuracy of the map. Where existing control must be used, the accuracy of the map will depend upon the density of this control, the accuracy of its location, and the accuracy with which it can be identified. Paragraphs 63 and 65 discuss the errors affecting multiplex triangulation. If the situation is such that the control net-

work can be planned, advantage should be taken of the multiplex equipment in bridging and only enough control established to be consistent with the scale and accuracy of the final published map. Paragraph 66 discusses the distance that can be bridged with the multiplex equipment to maintain a given accuracy.

(2) The accuracy of the map is affected to a very large extent by the accuracy of the horizontal control that is used. This is especially true in long extensions of control where it is necessary to extend control many times the length of the original base control. When control can be planned, a procedure should be used that will permit the position of horizontal control points to be established within 1/200 inch of their true horizontal position on the final publication scale of the map. A map complying with the accepted standards of accuracy will then result.

(3) Identification of existing control from aerial photographs presents many difficulties. Errors in identification directly affect the resulting accuracy of the map. If control information is very old, the positions are often difficult to recover. However, fairly satisfactory multiplex bridges have been made by the careful selection and identification of U. S. Geological Survey control on aerial photographs from old descriptions, without occupying the ground. Such a procedure is not recommended except when it is impossible to occupy the ground. When ground control has already been established and descriptions are available, if at all possible, the ground should be occupied, and the point recovered and marked upon the photograph. When new horizontal control is being established, points should be selected which will be identifiable for position in the multiplex model. Such identification should be as definite as possible, and the best type of points should be selected for this purpose. The best type of point is that found by a right angle intersection of cultural detail, such as road, fence, field, and ditch lines. Small isolated trees may be used where none of the above is available. Care should be used in selecting the horizontal control, so that any change that has occurred in the appearance of the terrain in the interval between the time of the field work and photography will not lead to misidentification.

c. Vertical control.

(1) For the most accurate map, there should be vertical ground control in the four corners of each multiplex model in order to give the strongest possible horizontalization. In instances where it is necessary to extend or bridge elevations, the accuracy of the map will decrease. The accuracy with which vertical control can be extended and bridged by multiplex triangulation is discussed in paragraphs 63, 65, and 66.

(2) Since the accuracy of the map is greatly affected by the accuracy of the vertical control used, it is highly important that the vertical control be of an accuracy that is consistent with the contour interval. One-tenth of the contour interval is normally sufficient to avoid errors due to this cause.

(3) Before using existing elevations as vertical control, a careful inspection should be made to be sure that the elevation of the point has not changed since the control was established, that the point can be positively identified, and that the ground surrounding the point is level. When there is any doubt about the accuracy of an elevation, that point should be discarded. When using existing vertical control or establishing new control, the following points should be considered. Vertical control points must be identifiable for elevation in the multiplex model or the point is worthless. The point need not be precisely determined for position. Thus a point surrounded by level ground will yield the same measurement in the model even though the exact point cannot be identified. Points along sloping ground are satisfactory for use as vertical control points, provided their position is determined. Points should be avoided that lie close to abrupt changes in elevation, such as cliffs, etc. Good photographic contrast aids the accuracy of measurement of a point in the multiplex model.

59. CHARACTER OF PHOTOGRAPHY.—The following characteristics of aerial photography directly affect the accuracy of multiplex mapping.

Most of the resulting errors are discussed under other headings.

a. Straight flight lines.—Crooked lines in themselves cause no error in the individual model, but they result in crab and make multiplex triangulation more difficult.

b. Crab.—Crab reduces the size of the stereoscopic model, which in turn makes parallax removal and horizontalization more difficult.

c. Overlap.—Excessive overlap reduces the base-altitude ratio. Insufficient overlap (less than 55 percent) makes control or pass point selection difficult.

d. Tilt.—The multiplex equipment allows the use of tilted photographs but excessive tilt may cause improper side lap or overlap. When the reduction factor is inaccurate, the large tilts in terrain of great relief may introduce noticeable errors.

e. Exposure and development.—Improperly exposed or developed film results in loss of detail. This in turn limits the ability of the operator to make proper interpretations, to attain accurate orientation, and to make accurate measurements.

60. ABILITY OF OPERATOR.—a. Stereoscopic perception.—The ability to distinguish a difference in depth varies with different people and with the nature of the object. At normal reading distance (10 inches), it is possible to recognize depth differences of from 0.05-mm to 0.15-mm. Training and practice will improve the ability of the normal person. The nature of the object viewed in multiplex operations depends upon its actual appearance and formation in nature, and upon the photography. When the image is clear and sharp, a perception of 0.05 mm is possible. This minimum will increase rapidly for images lacking good definition or contrast.

b. Nature of multiplex.—In stereoscopic range finders and similar instruments, the perception of depth is made more accurate by increasing the eye base and the magnification. The multiplex system is somewhat similar, but for clarity and proper relation of other errors the analogy has not been used. In effect, the eye base becomes the air base, the effect of which on the accuracy of ray intersection is referred to in paragraph 56. Magnification is controlled by the necessity of keeping the size of the projection equipment within reason. It should also be consistent with the quality of the projected images and the relation between stereoscopic perceptive ability and accuracy of the model.

c. Orientation.—Warpage of models results from improper orientation. Consistent results within the optical accuracy of the system can be obtained only by careful removal of vertical parallax from the model. The ability to remove parallax varies with the ability of different individuals, the nature of the images, and the character of the floating mark.

d. Spot heights and contour accuracy.—While careful stereoscopic location of a single point may be made from 0.05 mm to 0.15 mm, the process of tracing contours is usually performed in a continuous, more rapid manner. Larger errors may thus be expected in contours varying particularly with the terrain. (See par. 57.)

61. SUMMARY OF MULTIPLEX MODEL ACCURACY.—a. General.—No definite statement as to multiplex

Table of possible errors

Comparatively definite sources	Errors	Remarks
1. Multiplex equipment	±0.1 mm	Normal equipment.
	± .15 mm	Wide-angle equipment.
2. Aerial camera	± .1 mm	T–5, T–3A, or equal.
3. Photographic material	± .1 mm	Majority in diapositives.
4. Operator's ability	± .1 mm	Under good conditions.

Indefinite sources of error	Amount of error
1. Base-altitude ratio	Fixed for a given camera at 60 percent overlap, with increase or decrease in 1, 2, and 3 above, with departure therefrom.
2. Photography	Minimum if photograph complies with standard specifications. Increases with poor photography.
3. Control	Minimum with proper control. May be largest error of all with poor control.
4. Terrain	Varies with each project. Roughly minimum on hilly cultivated terrain.

accuracy will fit all cases. Many of the factors contributing to the resultant error vary so greatly that they can only be estimated for a particular project. The above table is a rough outline for ready reference.

b. Contour accuracy.—The first four errors in the above table are independent errors that are unlikely to occur in one place at one time in any one model. The combination of these errors in one model should not exceed ±0.2 mm. This is 1/1,800 of the flight altitude and represents one-half the contour interval. Therefore, the basic maximum accuracy of the Multiplex system may be considered sufficient for a contour interval of 1/900 or 1/1,000 of the flight altitude. This basic accuracy must be reduced in accordance with the last four sources of error listed in the above table. On most projects, the estimated accuracy may be considered sufficient for a contour interval of from 1/500 to 1/1,000 of the flight altitude.

62. ALTITUDE, SCALE, AND CONTOUR INTERVAL.

a. Altitude-contour interval.—The chart in figure 37, which is based on a factor of 1/500 to 1/1,000 as the ratio between contour interval and flight altitude, furnishes a guide in the selection of flight altitude. The exact choice depends on the particular project. Considering the accuracy of this chart and for convenience, an even 1,000-foot, or at least 100-foot, altitude should be selected.

b. Altitude-scale.—When an altitude is chosen based on the required contour interval, the plotting scale can be selected from figure 7. The plotting should be performed near the optimum projection distance which is 360 mm for the wide-angle and the normal projection. For convenience an even scale should be used, such as 1/20,000 rather than 1/19,675.

c. Battle maps.—A contour interval of 1/500 of the flight altitude is considered appropriate for the battle map. The

requirement for 50-foot contours is therefore satisfied up to an altitude of 25,000 feet. Battle-map control may be poor, in which case the contours fulfill the requirement of ½ contour-interval accuracy only with respect to the control or extended control used and not to datum. An altitude exceeding 25,000 feet may improve the accuracy of extended control by reducing the number of extended models, but the local accuracy with respect to that control would then deteriorate.

63. MULTIPLEX TRIANGULATION.— a. General.—In paragraph 40 there was given the procedure for extending control without the use of ground information by the orientation of additional projectors to two projectors already forming a stereoscopic model. This forms the basis for increasing the control network. The orientation of the second and succeeding models is not perfect, as certain unavoidable errors are involved. These errors are described below, the first two (distortion and datum errors) being rather regular in effect, while the latter two (personal and equipment errors) are usually unpredictable.

b. Distortion errors.—When any two projection lenses are not distortion-free, an effort to form a parallax-free stereo-

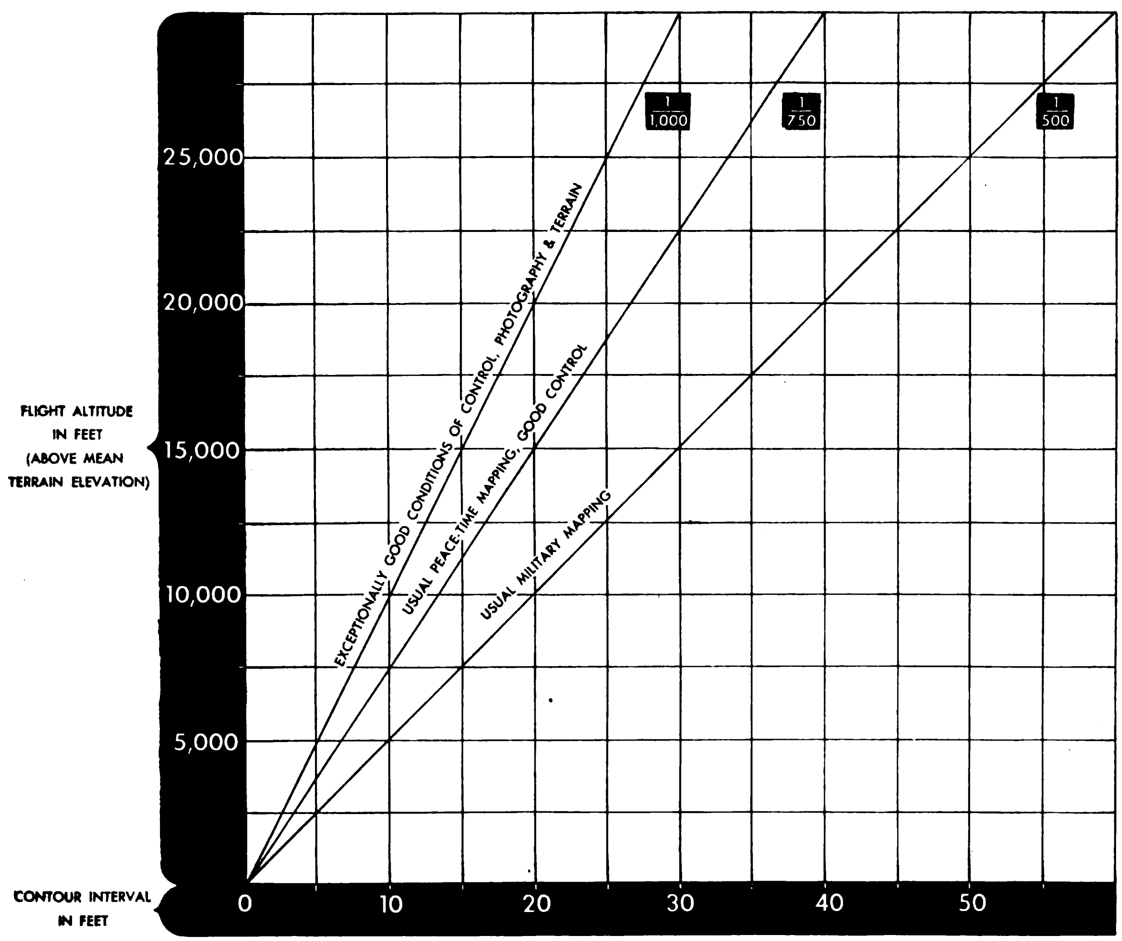

Figure 37.—Flight altitude and contour interval.

scopic model results in a false tip orientation of the projectors. The resultant stereoscopic model may be correct within the accuracy of reading, but the tips of the projectors will not correspond to those of the taking camera. Distortion in the taking camera lens and distortion in the reduction printer lens have the same effect. When a third projector is added without control, the tip of the second projector is not changed, and therefore the tip of the third projector will be in error by an increased amount. With uniform projectors, a gradual curve away from datum may be expected.

c. Datum errors.—Plotting the curved earth to a flat datum should result in a smooth curve departing from the flat datum by the amount of curvature. The effect should be similar to that caused by distortion. The departure from datum caused by curvature is noticeable only if other errors are small in comparison. Very high altitude photography is most likely to show it.

d. Personal errors.—Personal errors are of many kinds and are in no way predictable. Closely allied with them are errors in the aerial film and diapositives which may or may not be due to personal errors of handling. Direct personal errors are involved in all orientation procedures. These errors are usually sufficient to destroy the smooth curve away from datum expected from the distortion of camera, printer, and projection lenses, and from curvature of the earth.

e. Equipment errors.—Inaccurately constructed cameras or printers may directly cause cumulative errors other than from lens distortion and may indirectly cause unsystematic errors. Poorly constructed projectors cause local unpredictable errors. Mislocated principal points, warped stage plates, improper reduction factors, lack of parallelism in the printer planes, poorly located or defined collimating marks, and loose magazines are obviously possible sources of this type of error. With proper equipment, this class of error should not be large.

f. Effect of errors.—Errors are noticeable to the Multiplex triangulation operator by their effect on the six elements of orientation. The following remarks apply:

(1) *Tip.*—Lens distortion and curvature of the earth are most noticeable in their effect on tip. There is no way to neutralize this error with external aids. (See par. 64.)

(2) "*BZ*".—A false orientation of tip in turn involves a false value of "BZ." If a method could be devised for controlling one error, the other could be corrected.

(3) *Tilt.*—When an additional projector is oriented to a previous stereoscopic model, the second model may be tilted with respect to the first. This is commonly known as cross tilt and is discussed in paragraph 67. It may be due to faulty removal of parallax, faulty diapositives or photographs, or an undetermined error in the equipment.

(4) "*BX*".—False values of "BX" usually represent errors in scale. Poor starting control may cause an entire extension to be off scale, but even with good starting control, some variation in scale can be expected along the flight line. Carefully removing parallax and holding to pass points near each principal point reduce this error.

(5) *Swing and "BY"*.—Errors in these two elements represent a departure from the true azimuth. They are closely related to tilt errors. It is possible to remove cross tilt by introducing parallax with swing and "BY", but this normally increases the total azimuth error.

64. EXTERNAL AIDS TO CONTROL EXTENSION.

a. General.—The goal of many experiments has been the recovery of the camera position and

orientation at exposure. No scheme has as yet been adequately successful. The desirability of such data is evident since accumulation of the above-mentioned errors would then be impossible. Experiments tried or investigated include level bubble, gyro, and horizon recordings of tips and tilts; statoscope and altimeter recordings of altitude; and radio altimeter and bomb recordings of flight height (for scale).

b. Approximate solutions.—Mapping photography is performed at a constant flight altitude within the limits of the pilot's ability to hold this altitude and the instrumental accuracy of indicating the altitude. Thus, by making the assumption that the altitude in a particular strip is constant, it is possible to neutralize or to adjust to a certain extent the errors introduced by the false tip and resultant "BZ" errors. One method is to set all the projectors at the same height and make minor changes in the "BZ" locally where it is indicated that such a change will remove some of the parallax from the models and still will not cause the projectors to deviate greatly from a mean height. Perfect stereoscopic models are not formed by this method and, without perfect models, passing from model to model is hazardous, causing the scale accuracy normally to deteriorate. Another method, which is more desirable with the wide-angle equipment, is that described in paragraph 40*e*, in which a normal run is made and all parallax removed in the strip. By this method the scale of the extension is more accurate.

c. Recorded altitude.—The T–5 camera is equipped with an altimeter and a method of recording the altimeter readings on the negative at the instant of exposure. The recorded differences in altitude between exposures are fairly reliable and are used to advantage in adjusting the extended elevations instead of the constant altitude recordings. The absolute altitude, determined from these recordings by making the proper corrections for temperature and pressure, is not sufficiently accurate to be of much value.

65. PRACTICAL EVALUATION OF ERRORS IN MULTIPLEX TRIANGULATION.—a. General.—The factors affecting the accuracy of a multiplex extension are many and some of them vary so greatly that, as with the single model, the result can only be estimated for a particular project. Numerous test extensions have been made with the wide-angle equipment, using various cameras and camera-printer combinations. The results obtained in these tests give a good indication of the errors which will normally need to be reckoned with, where the extension is made under favorable conditions. The errors described in *b* to *f* below are expressed as a ratio of the distance extended. As the extension at the outset can be no more accurate than the starting control, any error in starting control must be added to these errors.

b. Scale, wide-angle equipment.—The average error in scale in an extension of a single strip of eight models was found to be about 1/890, and in sixteen models it was about 1/650.

c. Azimuth, wide-angle equipment.—The aximuth of a single strip does not hold as closely to true position as the scale. The extended strips follow a flat circular curve, sometimes to the left and sometimes to the right, depending upon the camera-printer combination used.

Tests have indicated that this curvature is an instrumental error which will vary with the combination used and is practically unpredictable for any particular combination. In one combination in which several strips of the same flight were extended by four operators independently, the average curvature was of such an amount that with both ends of a 16-pair strip on control, the positions in the center of the strip were in error by 2.8 mm. Subtracting this average rate of curvature from each strip extended with this camera-printer combination gave a remaining average azimuth error in an extension at eight models out of about 1/800, and at sixteen models out of about 1/600. The error due to this curvature is practically eliminated by adjusting two adjacent strips which have been flown in opposite directions. Thus the basic probable average accuracy for each strip where two or more parallel strips flown in opposite directions may be adjusted together, or for a single strip where it is found that a particular camera-printer combination gives no curvature, appears to be about as indicated above.

d. Resultant error, wide-angle equipment.—The errors in scale and azimuth give a resultant error in position for a single strip of 1/590 at eight models out and 1/445 at 16 models out from the base control. Where the strips in a particular project are flown in opposite directions and in such a way that an adjustment can be made between strips, the accuracy of position should increase with the number of strips extended and adjusted together. Ordinarily, it will not be practical to attempt to adjust more than six strips to each other. Based on the above resultant error for an average single strip, the probable error in position for various numbers of strips adjusted together would be as follows:

Number of strips	Resultant accuracy	
	At eighth plate pairs	At sixteenth plate pairs
1	1:590	1:445
2	1:840	1:630
3	1:1000	1:770
4	1:1180	1:890
5	1:1330	1:1000
6	1:1450	1:1080

e. Elevations, wide-angle equipment.— In all test strips the elevations were determined by making a constant altitude assumption and applying a correction to the extended Multiplex elevation, as discussed in paragraph 40*e*(4). The average error in elevation on the center line of the strip at eight models out from the base control was 0.9 mm with a range of error from 0 to 2.5 mm. At 16 models out the average error was 1.2 mm with a range of error from 0 to 3.0 mm. These errors are expressed in terms of the scale of the model. Points away from the center line of the strip will generally be found to be in error due to a tilting of the strip. This tilt, expressed as the difference in the height between the two edges of the model, averaged 0.8 mm at 8 models out, with a range of error from 0 to 2.3 mm, and at 16 models out averaged 1.5 mm with a range of error from 0 to 5.9 mm.

f. Normal multiplex.—The errors in triangulation with the normal Multiplex equipment will generally be greater than those given above for the wide-angle equipment because more models are required to extend a given distance; the ratio of width to length of strip is

smaller; the smaller angle of coverage and smaller base-altitude ratio make the removal of parallax less sensitive and hence the relative orientation less accurate; and the accuracy of the equipment in general is not as great as the wide-angle.

66. Multiplex bridging.—a. The errors of bridging are similar to the errors of a Multiplex triangulation, since bridging is a special case of triangulation wherein control is not furnished in every model but does appear at both ends of any series of uncontrolled models. In bridging, the accumulation of errors can be determined and adjusted throughout the intermediate models.

b. Horizontal accuracy.

(1) The maximum position error in a bridged section will vary with the number of models bridged and is of the same magnitude, at the scale of the Multiplex model, regardless of the flight altitude from which the exposures were made. Therefore, in order that an allowable error in position, expressed as a certain distance on the ground, will not be exceeded, fewer models may be bridged at the smaller scales. As a result of a number of test bridges, it has been determined that a position accuracy of 33 yards will be met ordinarily with the following scales and lengths of bridges with the wide-angle equipment, when the reproduction scale is the same as the mapping scale.

Mapping scale	Flight altitude (feet)	Number pairs	Distance (yards)
1:10,000	12,000	15	35,000
1:15,000	18,000	13	46,000
1:20,000	24,000	11	54,000
1:25,000	30,000	10	60,000
1:30,000	36,000	9	73,000

(2) In order to meet the accepted standard for horizontal map accuracy in peacetime mapping, which is that 95 percent of all well-defined cultural and planimetric features shall be shown within 1/60 of an inch of their true position at the publication scale of the map, the number of models which may be bridged will vary with the ratio of the scale of reproduction to the scale of the bridge. Based on the same results as above, the following are the number of models which may ordinarily be bridged satisfactorily at various reproduction scales.

Publication scale	Number of models
Scale of extension	5
3/4 extension	7
1/2 extension	9
1/4 extension	13

c. Vertical accuracy.—As in plotting single models, the vertical accuracy of bridging is more critical. With the wide-angle equipment the *BZ* curve must be used to adjust these elevations to a level datum; hence, the accuracy will depend to a certain extent upon the accuracy of the constant flight altitude assumption or the altimeter recordings where available. Additional corrections should be made for the tilt in the strip. Best results will be obtained by using two elevations at each end of the bridged section located near the edges of the strip. Actual tests show that bridges of sixteen models can thus be made with errors not exceeding 1.5-mm and an average error of 0.4-mm throughout the strip. Shorter bridges reduce the range of error somewhat but give about the same average error.

d. Normal multiplex bridging.—Tests have shown that for military mapping with the normal multiplex equipment, bridging up to the limit of the single frame can be accomplished without exceeding a horizontal error of 33

yards. It is estimated that nine projectors can be bridged with a normal maximum vertical error of 1 mm along the center line, while the edges may have errors of 1.5 mm or more.

67. CROSS TILT.—This phenomenon, mentioned in paragraph 63*f*(3), is particularly annoying in all multiplex triangulation. It is due to the inability to duplicate the recovery of the common camera station in successive pairs, which in turn is due to variations in the equipment or materials and imperfect relative orientation. Tests show that cross tilts can be eliminated from perfect photographs (grid diapositives), although some diapositives must be discarded. Hence, the main cause of cross tilt is imperfect orientation due to the inability of the operator to remove parallax from actual terrain plates. When cross tilt occurs, a recheck of the relative orientations must be made. If this fails to help, the diapositives should be exchanged. In no case should the cross tilt exceed 0.5 mm if proper care is taken. Introduction of swing parallax will remove the cross tilt, but will introduce an azimuth error. Several tests showed that removal of all crosstilt in a series of thirteen projectors by this method introduced a considerable bow in the strip.

APPENDIX I

NOTES ON TRAINING

1. GENERAL.—The primary requirement of a multiplex operator is good stereoscopic vision, which may be natural or acquired by training. The majority of people in normal daily life do not develop stereoscopic vision, but do possess it in varying degrees; with proper training it can be developed to the standard required of a multiplex operator. In addition to good stereoscopic vision, an operator must have a reasonable knowledge of mapping methods and be a fair draftsman. Training on these subjects should be included when necessary. The following may be considered as a guide and should be varied in accordance with the qualifications of the trainee.

2. STEREOSCOPIC TRAINING.—**a.** The student should be tested prior to any stereoscopic work to determine whether his stereoscopic vision is satisfactory. Such a test may be made using plates prepared for stereoscopic examination, in which different amounts of parallax are introduced into the figures presented. If the test shows that the student's stereoscopic vision is unsatisfactory, no further Multiplex training should be given to that individual. If his stereoscopic vision is satisfactory, additional stereoscopic training should be given to the student in order to improve his perception of depth. A student's response to training may be checked at intervals, using the plates prepared for stereoscopic examination.

b. Since stereoscopic observation consists of fusing two images, the first step in training is to increase the individual's power of fusion. This training need not be extensive; it may consist of practice in fusing two dots on a paper held about 12 inches from the eyes. The first attempt should be made with the dots ¼ inch apart, increasing the distance gradually to about 1½ inches. This practice should be continued until the eyes can fuse dots 1½ inches apart quickly and with little effort. The eyes should be rested if they become strained.

3. MULTIPLEX INSTRUCTION.—**a.** The student's introduction to the multiplex may consist of a demonstration of a terrain model; the student is shown

how to operate the tracing table, and the floating mark is placed in contact with the ground at some point for his inspection. Then, operating the table himself, the student places the mark on the ground several times in succession at five or six different points. By reading each setting the instructor is able to form an opinion of the acuity of the student's stereoscopic perception. The student should at this time draw a few contours and planimetry to demonstrate his grasp of what he is trying to learn.

b. If the student shows evidence of good stereoscopic vision, he is instructed in packing and unpacking the equipment and in setting it up. He is given the nomenclature and shown the movements of the projectors. A grid diapositive is inserted so that the student may observe the effects of projector movements. An identical grid is then placed in a second projector, the filters inserted, and the effects of movements of both projectors demonstrated to the student. He is then shown how to form a stereoscopic model by removing parallax, and is permitted to practice for about one day. The operator should perform this step by matching the colors in the projection without wearing the filter spectacles.

c. If the student is progressing satisfactorily, he puts on the spectacles and is shown how to remove parallax stereoscopically.

d. The next step is to teach horizontalization of the grids by moving the projectors and the bar.

e. The student should then be required to set up a pair of terrain diapositives, remove the parallax, scale and horizontalize the model. This practice will entail some instruction in projection sheet layout in the drafting room, and in using the conversion tables. He should again spend some time on contours and planimetry. The exercises described above should consume about one week.

f. The student should then make at least three runs over the same contour in order that the instructor (and the student as well) can judge his capabilities at this stage. If sufficient progress has been made, the student draws a complete terrain model, which, upon completion, is broken up and redrawn for comparison.

4. REMARKS.—a. It is considered advisable in instruction to demonstrate clearly and thoroughly, then leave the student to his own devices, emphasizing that he should ask questions whenever he has difficulties. Too much supervision tends to make the student self-conscious and backward.

b. The final step in instruction is demonstrating the method of adding additional projectors to the original pair extending or bridging control. This may occur long after the original instruction and in some organizations is confined to a few operators.

c. It is estimated that at least six months are required to train a competent operator, although he may work under supervision in about six weeks.

d. Students who cannot consistently read multiplex elevations of well-defined points to within .1-mm after stereoscopic training should not continue in training.

APPENDIX II

NOTES ON PLOTTING

1. GENERAL.—**a.** In order to attain the maximum efficiency and to insure the accuracy of topographic representation, it is advisable to follow a rather definite plan of procedure in plotting the multiplex models and to take certain precautions in each of the various steps. Generally, a number of operators are working at the same time on different portions of the area. The labor of coordinating and joining the work of different individuals can be reduced somewhat if each operator, or each unit, if working on a shift basis, is assigned an area or several adjacent pairs to plot. However, in certain instances, where speed is essential, all pairs are plotted simultaneously. In such cases, a definite policy as to woods and road classification, the amount of detail to be shown, and the type of symbols to be used must be set up and closely followed by each operator to insure uniform results.

b. Before plotting, it is advisable to scan the model to get a mental picture of the area and to plan the drawing of it. In plotting single models, contours are usually plotted first. When a bridged section is to be plotted without dismantling any projectors immediately following the scaling of the bridge, it is sometimes desirable to plot planimetry first.

c. During the drawing of a model, the lead in the tracing table must be kept sharp. The proper grade of pencil and proper pressure should be used to give a clean, thin line. The lines should be heavy enough to withstand the rubbing of the tracing table and still be visible when the plotting is completed. If the line drawn by the tracing table is not heavy enough, it should be retraced by hand. The portions of the plotting sheet which are not actually being worked upon should be kept covered.

d. It is advantageous to deaden the glossy painted surface of the tracing table screen to a dull finish by exposing the surface to the smoke of a burning magnesium ribbon. This deadening of the glossy surface stops the annoying reflection of the glare from the projection and breaks the light up into image reflections in place of glare.

2. CONTOURS.—a. Before plotting the contours, the horizontalization of the model should be checked and spot elevations at various prominent road intersections and hilltops should be read and recorded on the map sheet. It is best practice to start with the lowest contour in the model (or highest, if preferred) and trace that contour completely throughout the model wherever it occurs. The terrain should be carefully studied to be sure that the contour drawn is logical and that it fits the control and spot elevations before proceeding to the next contour. In models of low relief, best results will be obtained by tracing the contour several times, accepting the most logical one, and erasing the others from the sheet. It is not advisable to skip contours and fill in later. Generally, drawing successive contours will more faithfully represent the terrain.

b. When drawing contours, the illumination of both projectors should be equal. In models where the illumination balance is poor, the floating mark will appear to rise above the ground when it is moved in one direction parallel to the base line, and will appear to dig into the ground when moved in the opposite direction. This effect is generally more evident on the surface of smooth plateaus, but may occur in any type of topography. It is due to the fact that in scanning the model, the eye viewing the brighter image actually sees its image a split second ahead of the other. When the tracing table is held in one position, the floating mark may be readily placed in contact with the ground at its true elevation, hence this phenomenon will probably not be noticed while orienting the model.

3. PLANIMETRY.—The amount of detail to be plotted depends upon the type of map being produced. The operator should plot more detail than will be needed in order to be on the safe side. Certain types of maps require all the detail identifiable to be shown, while on others, especially maps which are to be reproduced at a small scale, plotting all of the detail in well developed districts would only clutter up the map sheet and serve no useful purpose. In this step standard topographic symbols may be deviated from when an easier and more logical symbol for pencil work can be used. The standard symbol can be applied in the final drafting. Fine drafting is not required of the multiplex operator, but it is imperative that his plotting be accurate and legible. When features are truly straight, such as portions of roads, fences, and woods lines, points should be plotted at both ends of the straight portion and then connected by using a straightedge. The hand stereoscope and contact prints should be used freely as an aid in proper identification. Where identification is doubtful, this should be noted on the plot.

4. PLOTTING EXTENSIVE AREAS.—a. In cases where it is necessary to bridge control, or where several successive pairs in a strip are assigned to an operator, the necessary number of diapositives to cover the area should be set up in the multiplex projectors at one time. By bridging, the scales of these models are adjusted to each other and the scale of the whole strip is adjusted to fit the horizontal control. If measurements are then made on all of the control points of the strip, it will be found that it is impossible to adjust the bridge so

that the true values of the control points are read, but the errors will not be great. The model elevations are not close enough to give the desired contour accuracy, but they are close enough so that horizontal position errors do not occur. With this orientation, it is usually desirable to draw the planimetry for the complete strip before horizontalizing each model independently for contours. It is best to average the vertical adjustment of the strip so as to fit all the vertical control as closely as possible. The positions may then be plotted throughout the adjusted strip without substantial error.

b. As a check on the adjustment of models, pass points between models should be measured near the edges of the strip as well as at the center. When the elevation of the center pass point is adjusted to read the same in both models, the elevations of the side pass points seldom are the same. The usual case is that there is a tilt between the datums of the two models with the two datums intersecting at the center of the model. This is known as "cross tilt." (See par. 67.) It indicates that there are still errors in relative orientation between the projectors of one or both models. When large cross tilts appear, a closer adjustment of the models should be attempted so that the cross tilt is reduced to a small amount, not more than 0.5 mm at the edges of the models. With models adjusted to that refinement, there will be no measurable position error in a short bridge (five or six models).

c. When the scale and orientation of the strip has been established, it is best to plot immediately some reference positions from the strip to serve as check positions later on. The crosses indicating the principal points on the diapositive are good marks to plot and serve other purposes as well. They are plotted by setting the tracing table to the elevation of the model at the cross. At the same time features around all sides of the strip should be plotted where other strips will join later. These will serve to indicate how the strips are tying together and help in their adjustment. The planimetry which is normally plotted does not always contain enough features to permit a proper tie between strips. For this reason, there should be plotted additional features, such as fence and field lines, small trails, and sharply defined woods and drain lines. Where nothing better exists, trees may be plotted. Following the plotting of the principal point crosses and a skeleton of the planimetry, the planimetry of the strip should be plotted.

d. A model at one end of the strip is next horizontalized, the plotting sheet reoriented to the planimetry already plotted, and the contours are plotted for that model. Other models of the strip are then horizontalized and contoured in succession.

e. When it is necessary for an operator to join his work with plotting already completed, it is essential that he have transferred to his sheet the edges of the ones joined in order to insure proper matching. The work should be planned so that these transfers are kept to a minimum and are made far enough ahead of actual need so as to cause no delay in the plotting.

Multiplex plotting scale	Contour interval		Flight altitude in feet for optimum projection plane	Value in feet of 0.1 mm at plotting scale	T-3A Camera			K-3B (8¼-inch) Camera				K-3B (6-inch), K-17 (6-inch), T-5 Cameras		
	1/500 Alt.	1/1000 Alt.			Photograph scale	Width of photograph in miles	Area of photograph in square miles	Photograph scale	Width of photograph in miles dimension 9-in.	Width of photograph in miles dimension 7-in.	Area of photograph in square miles	Photograph scale	Width of photograph in miles	Area of photograph in square miles
1:2400	5.7	2.8	2,840	0.787	1:5770	0.50	0.25	1:4110	0.58	0.46	0.27	1:5680	0.81	0.66
1:3600	8.5	4.3	4,250	1.181	1:8660	0.75	0.57	1:6170	0.88	0.68	0.60	1:8500	1.21	1.46
1:4000	9.5	4.7	4,730	1.312	1:9620	0.84	0.70	1:6860	0.97	0.76	0.74	1:9460	1.34	1.80
1:4800	11.3	5.7	5,670	1.575	1:11540	1.00	1.00	1:8230	1.17	0.91	1.06	1:11340	1.61	2.59
1:5000	11.8	5.9	5,910	1.641	1:12020	1.04	1.09	1:8570	1.22	0.95	1.15	1:11820	1.68	2.82
1:6000	14.2	7.1	7,090	1.969	1:14430	1.25	1.57	1:10290	1.46	1.14	1.66	1:14180	2.01	4.04
1:7000	16.5	8.3	8,270	2.297	1:16830	1.46	2.14	1:12000	1.71	1.33	2.26	1:16540	2.35	5.52
1:7200	17.0	8.5	8,510	2.362	1:17320	1.50	2.26	1:12340	1.75	1.36	2.39	1:17020	2.42	5.86
1:8000	18.9	9.5	9,450	2.625	1:19240	1.67	2.79	1:13710	1.95	1.52	2.95	1:18900	2.68	7.18
1:8400	19.8	9.9	9,920	2.756	1:20200	1.75	3.08	1:14400	2.05	1.59	3.25	1:19840	2.82	7.95
1:9000	21.3	10.6	10,630	2.953	1:21640	1.88	3.53	1:15430	2.19	1.71	3.74	1:21260	3.02	9.12
1:9600	22.7	11.3	11,340	3.150	1:23090	2.00	4.02	1:16460	2.34	1.82	4.25	1:22680	3.22	10.37
1:10000	23.6	11.8	11,810	3.281	1:24050	2.09	4.36	1:17140	2.44	1.89	4.61	1:23620	3.36	11.29
1:12000	28.4	14.2	14,180	3.937	1:28860	2.51	6.28	1:20570	2.92	2.27	6.64	1:28360	4.03	16.24
1:14000	33.1	16.5	16,540	4.593	1:33670	2.92	8.54	1:24000	3.41	2.65	9.04	1:33080	4.70	22.09
1:14400	34.0	17.0	17,010	4.725	1:34630	3.01	9.04	1:24690	3.51	2.73	9.56	1:34020	4.83	23.33
1:15000	35.4	17.7	17,720	4.922	1:36070	3.13	9.80	1:25720	3.65	2.84	10.38	1:35440	5.03	25.30
1:16000	37.8	18.9	18,900	5.250	1:38480	3.34	11.16	1:27430	3.90	3.03	11.81	1:37800	5.37	28.84
1:18000	42.5	21.3	21,260	5.906	1:43290	3.76	14.12	1:30860	4.38	3.41	14.94	1:42520	6.04	36.48
1:20000	47.2	23.6	23,620	6.562	1:48100	4.18	17.43	1:34290	4.87	3.79	18.45	1:47240	6.71	45.02
1:22000	52.0	26.0	25,990	7.218	1:52910	4.59	21.10	1:37720	5.36	4.17	22.32	1:51980	7.38	54.46
1:24000	56.7	28.4	28,350	7.874	1:57720	5.01	25.10	1:41140	5.84	4.55	26.56	1:56700	8.05	64.80
1:26000	61.4	30.7	30,710	8.530	1:62530	5.43	29.48	1:44570	6.33	4.92	31.14	1:61420	8.72	76.04
1:28000	66.1	33.1	33,070	9.186	1:67330	5.84	34.11	1:48000	6.82	5.30	36.15	1:66140	9.39	88.17
1:30000	70.9	35.4	35,430	9.843	1:72140	6.26	39.19	1:51430	7.31	5.68	41.52	1:70860	10.06	101.20

CAMERA DATA:	*T-3A*	*K-3B (8¼")*	*K-3B (6"), K-17 (6"), T-5*
Average focal length	149.7 mm	210.0 mm	152.4 mm
Focal plane dimensions	5.5" x 5.5"	7" x 9"	9" x 9"
Angular coverage across focal plane axis	50°–01′	45°54′, 57°07′	73°44′
Angular coverage across focal plane diagonal	66°–50′	60°10′	93°22′

APPENDIX IV

GLOSSARY

Absolute orientation.—See *orientation.*

Absolute parallax.—See *parallax.*

Air base.—Distance the airplane moved between two consecutive camera stations: see *base line.*

Angle of coverage.—The maximum angle subtended at a lens by light rays forming the image.

Base line.—Line connecting the lens nodes of adjacent Multiplex projectors. Corresponds to and is a miniature representation of the air base.

Bridging.—Extension of control by Multiplex or radial triangulation in which control exists at both ends of one or more uncontrolled models; see *Cantilever extension.*

Cantilever extension.—Extension of control by Multiplex or radial triangulation in which no control or tie point exists at one end of the triangulation; see *Bridging.*

Cartography.—The science and art of expressing graphically, by means of maps and charts, the known physical features of the earth's surface, and often including the works of man and his varied activities.

Coated lens.—A lens whose air-glass surfaces have been coated with a thin transparent film of such index of refraction as to minimize the loss of light by reflection. This reflection loss of uncoated lenses amounts to about 4 percent per air-glass surface.

Collimating marks.—Marks on the lower pressure plate of the reduction printer to which the negative is oriented; see *fiducial marks.*

Compensator lens.—Lens used in a reduction printer to compensate for annular change in density from the center of an aerial photograph negative.

Compilation.—Process of extracting map detail from aerial photographs and/or other sources to fit a control network in the preparation of a map.

Complementary colors.—Colors which, when added together, such as by projection, produce white light.

Condenser.—A lens or lens system so designed as to concentrate the illumination from a light source upon a limited area.

Conjugate distance.—The corresponding distances of object and image from a

lens. For every position that an object may occupy with respect to a lens, there is a corresponding position for the image. These distances are called *conjugate distances*.

Contour.—An imaginary line connecting the points on a land surface that have the same elevation; also the line representing this on a map.

Control.—A system of relatively accurate measurements to determine the distances and directions or differences in elevation between points on the earth and upon which depends a system of lesser accuracy.

Geodetic control.—Control which takes into account the size and shape of the earth, that is, system of points of known latitude, longitude, and elevation.

Ground control.—Control obtained by ground surveys as distinguished from control obtained by photogrammetric methods.

Horizontal control.—Control which determines horizontal positions only, as with respect to parallels and meridians, or to other lines of reference.

Multiplex control.—Control established from other existing control by bridging or by cantilever extension.

Recovered control.—Control previously established from other sources, which can be identified.

Starting control.—Control available for the absolute orientation of the first plate pair along a line of flight for which control is to be extended.

Vertical control.—Control which determines positions with respect to elevations only.

Crab.—Angle between the edge of a photograph and the flight line.

Cross tilt.—Relative tilt between the datum planes of two stereoscopic models formed when a third projection is added to two existing projections.

Culture.—Those features of terrain that have been constructed by man such as roads, trails, buildings, and canals; also boundary lines; and all names and legends.

Datum.—A reference element, such as a line, or plane, in relation to which the positions of other elements are determined.

Diapositive.—Positive print on glass used in projecting a view with a Multiplex projector.

Distortion.—One of the aberrations of a photographic lens which causes images to be relatively displaced from their true position as occurring in nature. This deformation is normally symmetrical about the optical axis of the lens.

Dodging disc.—Disc inserted between the lower pressure plate and the diffusing glass of a reduction printer to compensate for other than annular changes in density in an aerial photograph negative; see *compensator lens*.

Extended control.—See *control*.

Fiducial marks.—Index marks rigidly connected with the camera lens through the camera body and forming images on the negative which defines the principal point of the photograph.

Filter.—Any transparent material which absorbs a certain portion of the spectrum.

Floating mark.—A mark in the center of the tracing table which is physically raised and lowered within the spatial model to determine the elevation of ground points.

Focal length.—Perpendicular distance between the image plane and rear node of lens when the lens is set to project light rays.

Focus.—Characteristic of a photographic lens. A lens is said to be in focus when the lens is so placed with

respect to the image plane that best definition of the image results.

Forward lap.—See *overlap*.

Horizontal control.—See *control*.

Horizontal parallax.—See *parallax*.

Horizontalization.—Leveling of the spatial model, bringing it into agreement with vertical control. Horizontalization is a step in *absolute orientation*.

Hypsography.—Parts of a map, such as contours and contour numbers, which represent relief; see *cartography* and *planimetry*.

Interior orientation.—See *orientation*.

Manuscript.—Original completed work of multiplex topographers or compilers. See *compilation* and *topography*.

Model.—See *stereoscopic model*.

Multiplex extension.—*Cantilever extension* by means of the multiplex equipment.

Multiplex projector.—See *projector*.

Negative.—A sensitized plate or film which has been exposed in a camera and has the lights and shades in inverse order to those of the original subject.

Nodal point.—One of two points on the optical axis of a lens (or system of lenses) such that a ray emergent from the second point is parallel to the ray incident at the first. This first nodal point is also referred to as the *front nodal point*, or *incident nodal point*, and the second point as the *rear nodal point* or *emergent nodal point*. Also called simply *node*, as front node.

Optical axis.—The optical axis of a lens is a straight line which passes through the centers of curvature of the lens surfaces. In a compound lens if the centers of curvature of all the components were to lie in one straight line, this line would be the optical axis of such a lens. This exact condition is rarely obtained in practice.

Orientation.

Absolute orientation.—Orientation of two or more Multiplex projectors to give a stereoscopic model having correct scale and horizontalization.

Interior orientation.—Centering of the diapositive in a Multiplex projector by bringing the principal point of the diapositive into coincidence with the principal point of the projector. See *principal point*.

Relative orientation.—Orientation of one Multiplex projector with reference to another to produce the relative relationship of the taking cameras. Two adjacent projectors are relatively oriented when all rays from one intersect corresponding rays from the other.

Overlap.—Amount by which one photograph overlaps the area covered by another, customarily expressed as percentage. The overlap between aerial photographs in the same flight is distinguished as *forward lap* and the overlap between photographs in adjacent parallel flights is called *side lap*.

Overlay.—A record on a transparent medium to be superimposed on another record.

Parallax.

Absolute stereoscopic parallax.—Considering a pair of truly vertical photographs, of equal principal distances, taken from equal flight altitudes, or a pair of rectified photographs, or a stereoscopic model formed by the Multiplex projectors of such photographs, the absolute stereoscopic parallax of a point is the algebraic difference, parallel to the base line, of the distances of the two images from their respective principal points. It is a measure to scale of the height of the image in space.

Residual paralax.—Small amounts of Y-parallax which may remain in the model after relative orientation.

X-parallax or horizontal parallax.—Synonymous with absolute stereoscopic parallax; also used in Multiplex operations to denote the component of distance between two point images in a direction parallel to the vertical plane containing the base line.

Y-parallax or vertical parallax.—The difference of the perpendicular distances of the two images of a point from the vertical plane containing the base line.

Pass point.—A point whose horizontal and/or vertical position is determined in the Multiplex model, and which is intended for use after the manner of a ground control point in the orientation of other models, or for maintaining the scale of a strip when passing from model to model in a Multiplex triangulation.

Perspective center, perspective point.—The point of origin of a bundle of perspective rays. In a survey photograph the rear node of the lens is the perspective center of the photograph and the front node of the lens is the perspective center of the object.

Photogrammetry.—The science and art of obtaining reliable measurements from photographs.

Photograph.—A general term for a positive or negative picture made by a camera on plate, film, or other medium.

Picture points.—A point, the exact location of which can be readily spotted on the aerial photographs used in photo-mapping.

Planimetry.—Parts of a map which represent everything except relief, that is, works of man and natural features, such as woods and waters.

Plate pair.—See *stereoscopic pair*.

Plotting scale.—The scale of the Multiplex model or the scale at which the map is compiled.

Principal distance.—In the Multiplex projector, the distance from the rear node of the lens to the apparent plane of the diapositive or the physical distance from the rear node to the top of the stage glass corrected for the thickness of the stage glass. In general, it is the perpendicular distance from the perspective center to the plane of the negative photograph, or diapositive.

Principal point.—Foot of the perpendicular from the inner node of the lens to the focal plane of the camera (projector).

Print.—A photographic copy made by projection or contact printing from a photographic negative or from a transparent drawing as in blue printing.

Projection distance.—Distance from the front node of the lens to the plane of projection.

Projector, Multiplex.—Piece of Multiplex equipment which projects a reduced copy of the aerial negative.

Ray of light.—The geometrical conception of a single element of light propagated in a straight line and of infinitesimal cross section, used in tracing analytically the path of light through an optical system.

Recovered control.—See *control*.

Reduction printer.—Special printer used to make diapositives from original aerial negatives for Multiplex use.

Refraction.—The bending of light rays when light passes from one transparent medium to another.

Relative orientation.—See *orientation*.

Scaling.—Alteration of the scale of a stereoscopic model to bring it into agreement with a plot of horizontal control. Scaling is a step in absolute orientation.

Side lap.—See *overlap.*

Spatial model.—See *stereoscopic model.*

Stage plate.—Glass plate upon which the diapositive is placed in a Multiplex projector.

Starting control.—See *control.*

Stereoscope.—An optical instrument for assisting the observer to view two properly oriented photographs, to obtain the mental impression of a three-dimensional model.

Stereoscopic model.—An optical three-dimensional reconstitution, usually in miniature, of an object or view by means of superimposed projected images of a stereoscopic pair, or by viewing a stereoscopic pair either directly or with the aid of a stereoscope.

Stereoscopic pair.—Two photographs of the same area taken from different camera stations in such a manner that a portion of the area appears on both photographs. Also called a stereogram.

Stereoscopic triplet.—Two successive stereograms or stereoscopic pairs in the same flight or strip.

Swing.—Rotation of a Multiplex projector around its vertical axis. Rotation of a photograph in its own plane around the photograph perpendicular.

Tilt.—Rotation of a Multiplex projector around the *X* axis, or that component of absolute tilt in a photograph which is perpendicular to the line of flight.

Tip.—Rotation of a Multiplex projector around the *Y* axis, or that component of absolute tilt in a photograph which is parallel to the line of flight.

Topography.—Natural configuration of the surface of the ground, including relief, woods, and waters.

Topographic map.—A map which presents the horizontal and vertical position of the features represented; distinguished from the planimetric map by the addition of relief in measurable form.

Tracing table.—Piece of Multiplex equipment used for viewing the stereoscopic model, measuring the elevations in that model, and compiling the detail on a map plot.

Transverse axis.—The axis of rotation for which there is no displacement in the projection plane of an image in the diapositive plane when the lens is rotated. The transverse axis intersects the optical axis at a point through which passes the line joining an object and its corresponding projected image. The transverse axis is not a fixed point in a lens; its location is dependent upon the magnification.

Vertical control.—See *control.*

Vertical photograph.—An aerial photograph made with the camera axis as nearly vertical as practicable in an aircraft.

Wide angle lens.—A photographic lens having an unusually large angular field. There is no definite division point between an ordinary and a wide angle lens, but, in general, a wide angle lens has an angular field of greater than 80°.

"X" motion.—Movement of a Multiplex projector along the Multiplex base bar.

"Y" motion.—Movement of a Multiplex projector along a line perpendicular to the Multiplex base bar.

Y-Parallax.—See *parallax.*

"Z" motion.—Movement of a Multiplex projector vertically to adjust projection distance.

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